MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

NOVEMBER•DECEMBER 1999

TR CENTENNIAL ISSUE

100 Young Innovators

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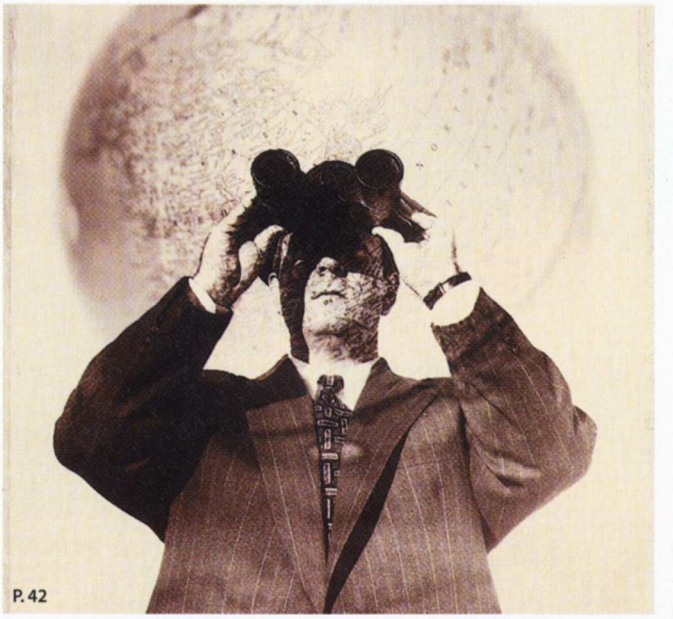

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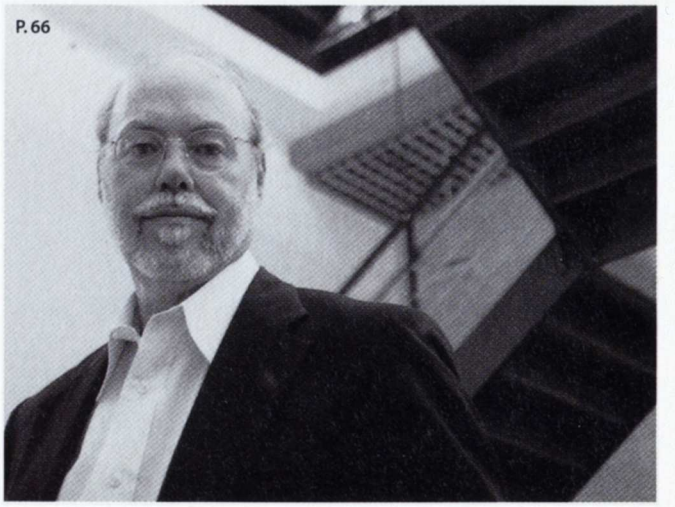

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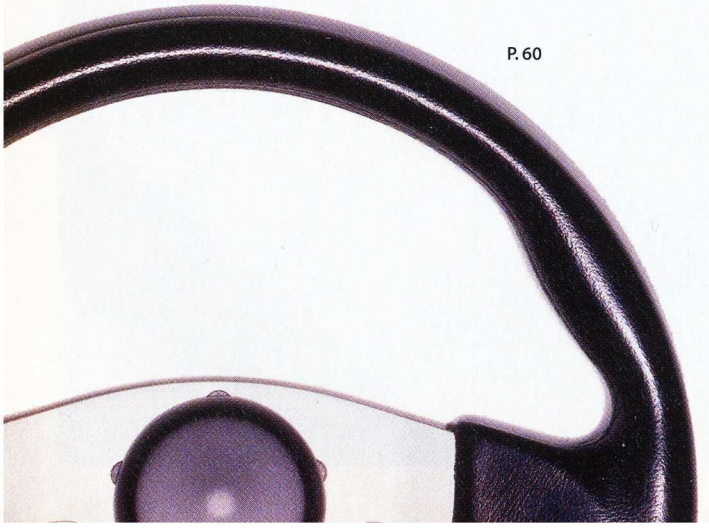

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Cover photo-illustration by Pierre-Yves Goavec

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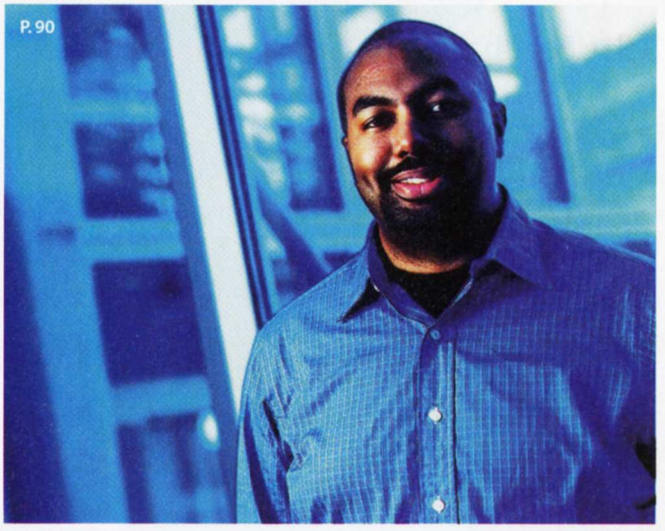
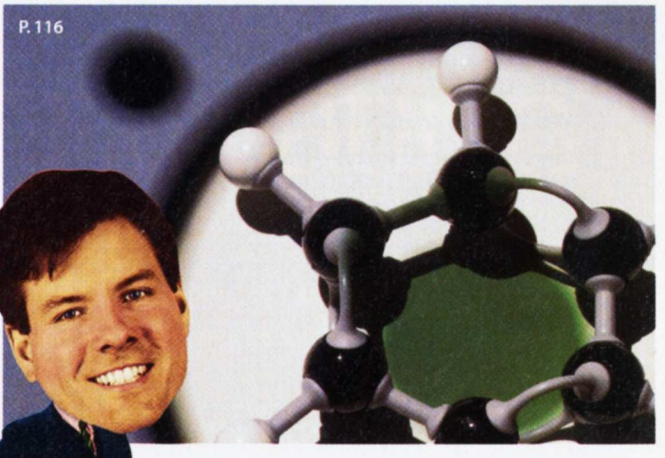
Technology Review 100

Meet 100 young innovators poised to shape technology. See the future through their eyes, starting on p. 73.





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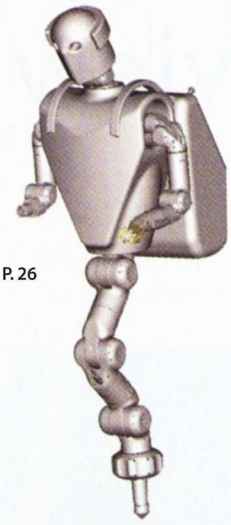
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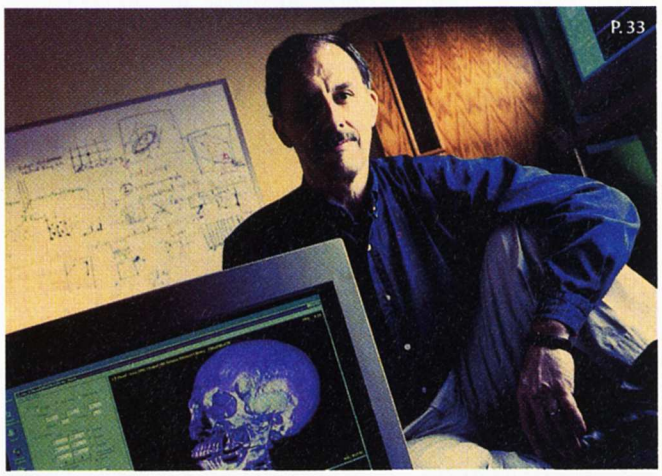
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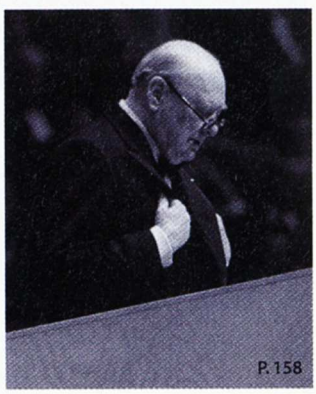
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Saluting the Spirit of Innovation

Home to nearly 5,000 of the world's most innovative companies, The Nasdaq Stock Market® understands and appreciates what it takes to turn great ideas into success stories.

In keeping with this spirit, Nasdaq® salutes the TR100: The Top 100 Young Innovators as chosen by MIT's Technology Review.

Here's to the future of technology – and what the next 100 years will bring.

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INDEX *People and Organizations in Our Articles*

A separate index of the TR100 may be found on page 142.

PEOPLE

ORGANIZATIONS

"European Air War's outstanding gameplay and wealth of features make it the current leader of the WWII simulation crop" *-PC Gamer, 89%, Editor's Choice Award*

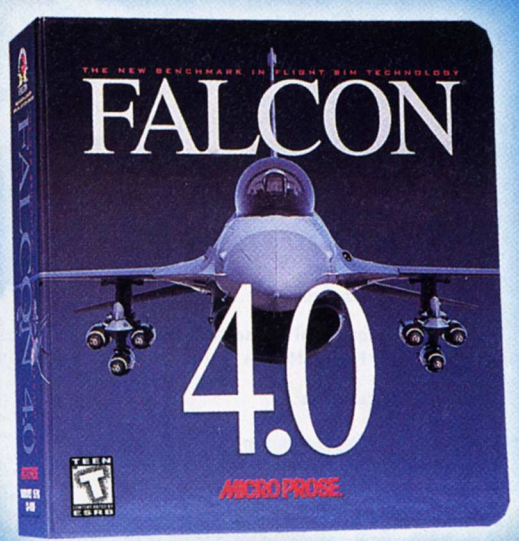
"This World War II simulation captured the feeling of being in a living, unpredictable combat environment better than any other sim released this past year" *-Computer Gaming World, 4 stars*

"European Air War succeeds at providing the experience that makes arm-chair fighter pilots believe they're truly leaving their mundane surroundings behind" *-Gamespot*

RACKING UP

"No previous sim covers so many different weapons and so many tasks in detail... it's all here and it's all beautifully executed" *-PC Gamer, 95%, Editor's Choice Award*

"Falcon 4.0 is the deepest, most complex air combat sim yet... The campaign also creates the greatest sense of playing a small but important part of a huge battle" *-PC Gamer*



"Thoughtful gameplay design and the effort to bring players a sense of the true fighter pilot's experience can be felt throughout the game" *-Computer Games Strategy Plus*

"European Air War combined huge dog fights, a great campaign system and realistic physics to make a game that was very hard to put down"
-IGN PC.com, Sim of the Year

"The care and attention to detail that went into every aspect of European Air War, from the hefty manual to the bomber nose art, represents a serious achievement"
-CNET GameCenter

THE KILLS!

"Bottom line: this sets the new standard in flight sims"
-Washington Post

"Falcon 4.0 is an incredibly detailed simulation that in many ways exceeds training systems in military use."
-Computer Gaming World

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100 Hot Zones

Although the readers of the 1899 Technology Review might not recognize the magazine you hold in your hands, this year marks our 100th year of continuous publication. This special issue was developed to commemorate a century of publishing history.

How to celebrate our centennial? When that question was raised last year, we quickly decided we weren't going to publish an issue devoted to the past. Lots of magazines are doing that this year. The newsstands are filled with special issues on the "100 Best This" or the "100 Best That" of the century now wobbling to a close. Not us. The new *Technology Review* is focused on the future. We decided the best way to conclude a century of publishing was to talk about the *next* century.

That left us with a problem: The next century hasn't happened. And most attempts to discuss the future, particularly the technological future, get very speculative very fast. This issue contains our solution to this problem: The TR100.

The TR100 are a group of young folk (under 35) who exemplify the spirit of innovation. They're from universities and big companies, startups and government labs, and from every significant arena the new *TR* covers: biotechnology, information technology, materials science, business, entertainment, policy—even digital art. The editors of *TR*—with the help of a distinguished Panel of Judges *(see p. 137)*—selected them because they have the potential to make big contributions in these fields in the decades to come.

Picking 100 young innovators is intriguing in itself. But it has an important collateral benefit: It's a way to identify areas of research that will pay off in the near future. The young have an urgent need to identify growth areas—because they're betting promising careers on their choices. As a result, reading the profiles we've written of the TR100 offers a guided tour of technology's "hot zones": the areas that the best and brightest believe will pay off during the next decade. That guided tour alone is worth the price of admission. But in addition, we've asked the TR100 to tell us what they think are the most significant trends emerging in hardware, software, biotech, materials and the World Wide Web.

The emphasis in this issue is on the young and on the future. Yet no generation invents itself; it must rely on the counsel and example of its predecessors. In that spirit, we asked Steve Hall, *TR* columnist and our nation's best chronicler of biomedicine, to interview Nobel Prize winner Phil Sharp on key developments in biotech. We asked Bob Metcalfe, inventor of Ethernet and founder of 3Com, to tell young innovators what he has learned as a successful inventor and innovator (he thinks the two are very different).

In the end, in spite of our best intentions, we couldn't resist a little summing up of the closing century: We picked the century's 10 most notable human-machine interfaces. But even that exercise has a forward spin. We chose interfaces because we believe that in the next century humans will become increasingly intimate with their machines and interfaces will grow dramatically in importance.

We hope you enjoy this forward-looking celebration of our first century of publication. Over the course of *TR*'s next century, we promise to continue bringing you the future as it happens.

—John Benditt

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TECHNOLOGY REVIEW

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"Ease of use" is not enough.
For years, our industry has worked on it: making technology conform to people, not the other way around. And to be honest, we haven't done a very good job. Sure, computers might be easier to use today than a few years ago, but they're still baffling many. At IBM, we are dedicated to the cause and we're taking some radically different approaches. As technology becomes smaller, faster, cheaper, more embedded in the fabric of our days, we believe technology and the solutions we invent should deliver something much more: ease of life.
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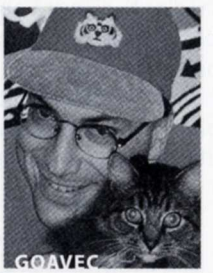
The road to innovation is rarely direct. Nowhere is this fact so keenly felt as in biotechnology, a field where **Stephen Hall** says pioneering companies have "a long history of going North when they wanted to go South, and when they should have gone East." In this issue Hall takes a break from his Biology Inc. column for a conversation with Nobel laureate Phillip Sharp. In "Biotech on the Move," the pair discuss biotech's two decades of triumphs and troubles, and their hopes and concerns for its future. Hall, who lives in Brooklyn, is also a contributing writer for *The New York Times Magazine* and the author of *A Commotion in the Blood* (Henry Holt & Co.).

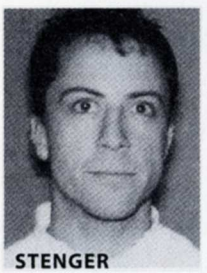

HALL

Not only is innovation circuitous—it's also very difficult to measure. And yet, for companies large and small, success may depend on knowing how much of this golden resource they have, and what they can do to get more. "In Search of Innovation" by *TR* contributing writer **Robert Buderi** gets to the bottom of today's innovation metrics, and concludes they've got a long way to go. Buderi takes a more anecdotal approach to winning R&D strategies in his upcoming book *Engines of Tomorrow: How the World's Best Companies Are Using Their Research Labs to Win the Future* (Simon & Schuster). Look for it on bookshelves starting in May 2000.

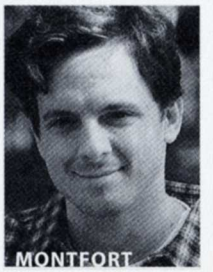
Photoillustrator **Pierre Goavec,** who created this issue's cover image and the illustrations that accompany the TR100 Special Section, says his unusual style was shaped by a childhood spent traveling with his parents through Africa and the Middle East. "There was no Toys 'R' Us," he explains, "so I had to make my own toys out of whatever I could find." Objects of all sorts are now a centerpiece of Goavec's style. In fact, he's got a mini-warehouse in his studio full of rubber limbs, computer parts and "just about everything else." Goavec uses these props, along with light and shadow, to create visual interpretations of abstract ideas.


GOAVEC

For innumerable contributions to the TR100 section, a laurel goes to TR100 coordinator **Brad Stenger.** A Georgia Institute of Technology graduate student in human-computer interfaces, Stenger spent the summer here on Vassar Street assembling dossiers on hundreds of TR100 candidates. Stenger says that after learning about all these incredible young technologists he wants to become...a professional journalist! See Stenger's story on career choices on p. 125.


STENGER

Another TR100 contributor who sees a path from technology to the written word is **Nick Montfort.** A recent graduate of MIT's Media Lab, Montfort lives in New York City where he composes interactive fiction. His latest work is *Winchester's Nightmare,* an online tale of technology and the American dream where the reader co-authors the story of an heiress to an arms fortune. (The novel will be on display at Digital Arts and Culture '99, an exhibition taking place in Atlanta, Ga., this October.) Collaboration was also Montfort's theme for his report in this issue on young researchers cooperating via the Internet.


MONTFORT

Assistant Editor **Deborah Kreuze** makes her first feature contribution to *TR* in this issue: a review of the century's top ten human-machine interfaces. In her own life, Kreuze also focuses on some of the 20th century's notable artifacts; she's an MIT graduate in music who has sung much of the repertoire of atonal compositions. But that's a tough way to make a living; like Stenger and Montfort, she's chosen publishing as a career. TR

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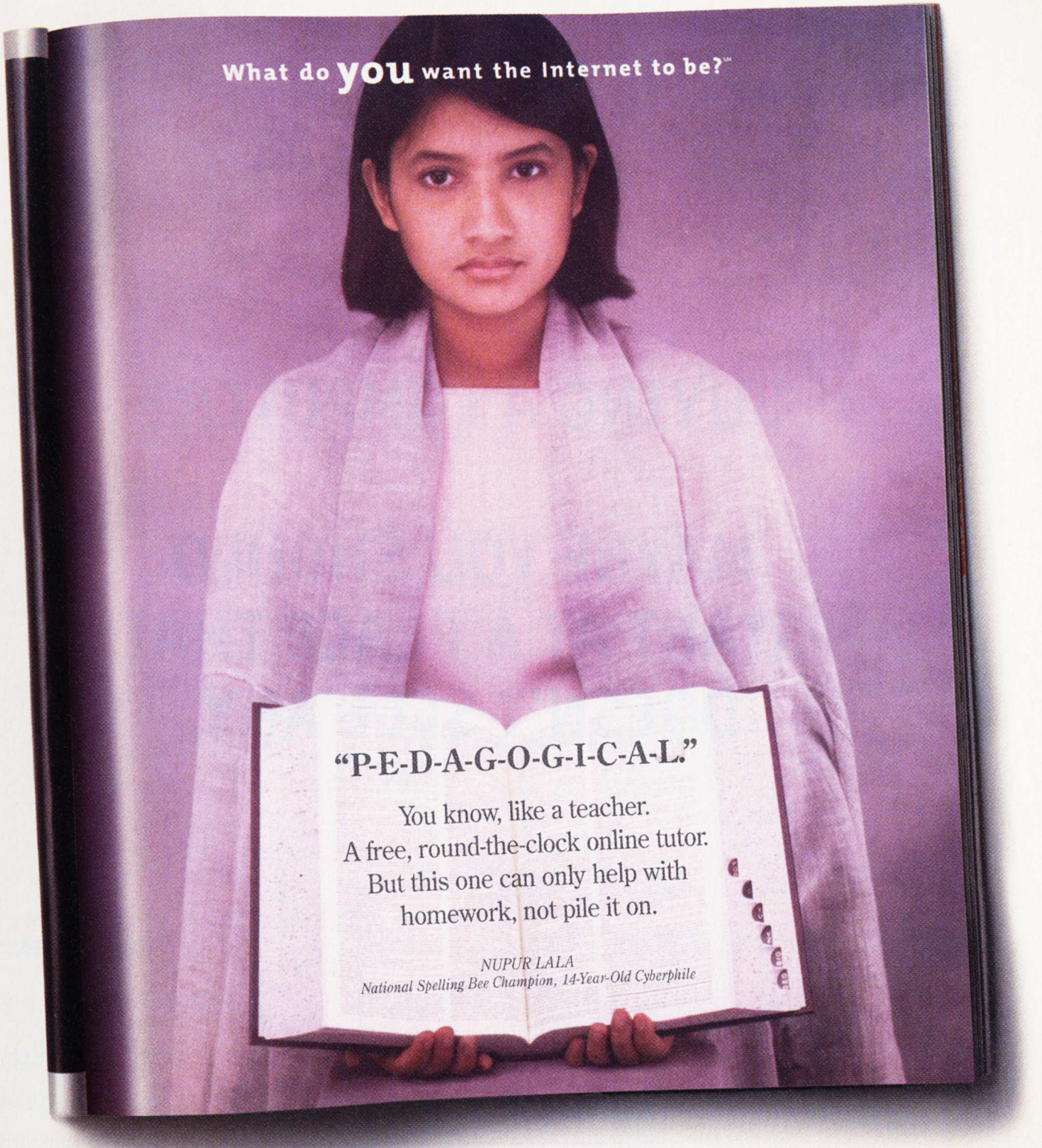

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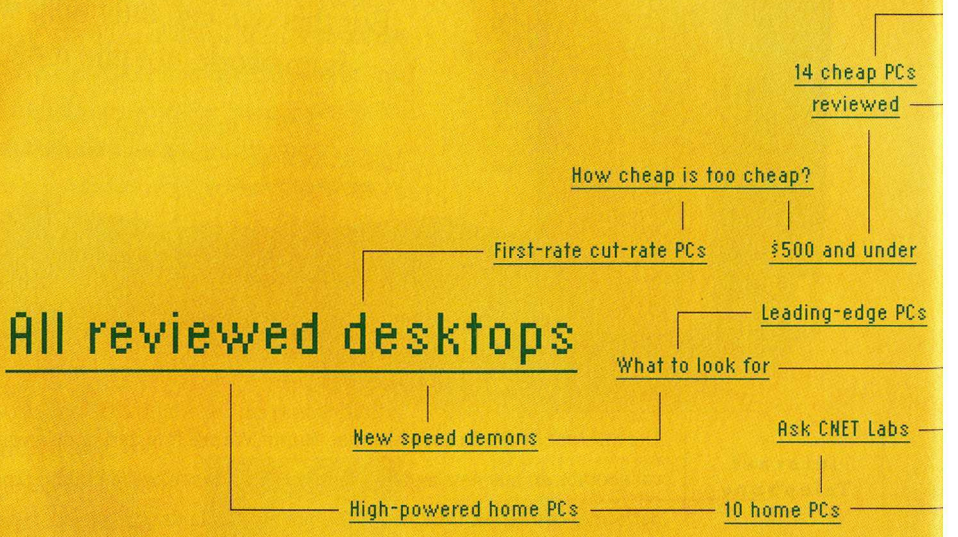

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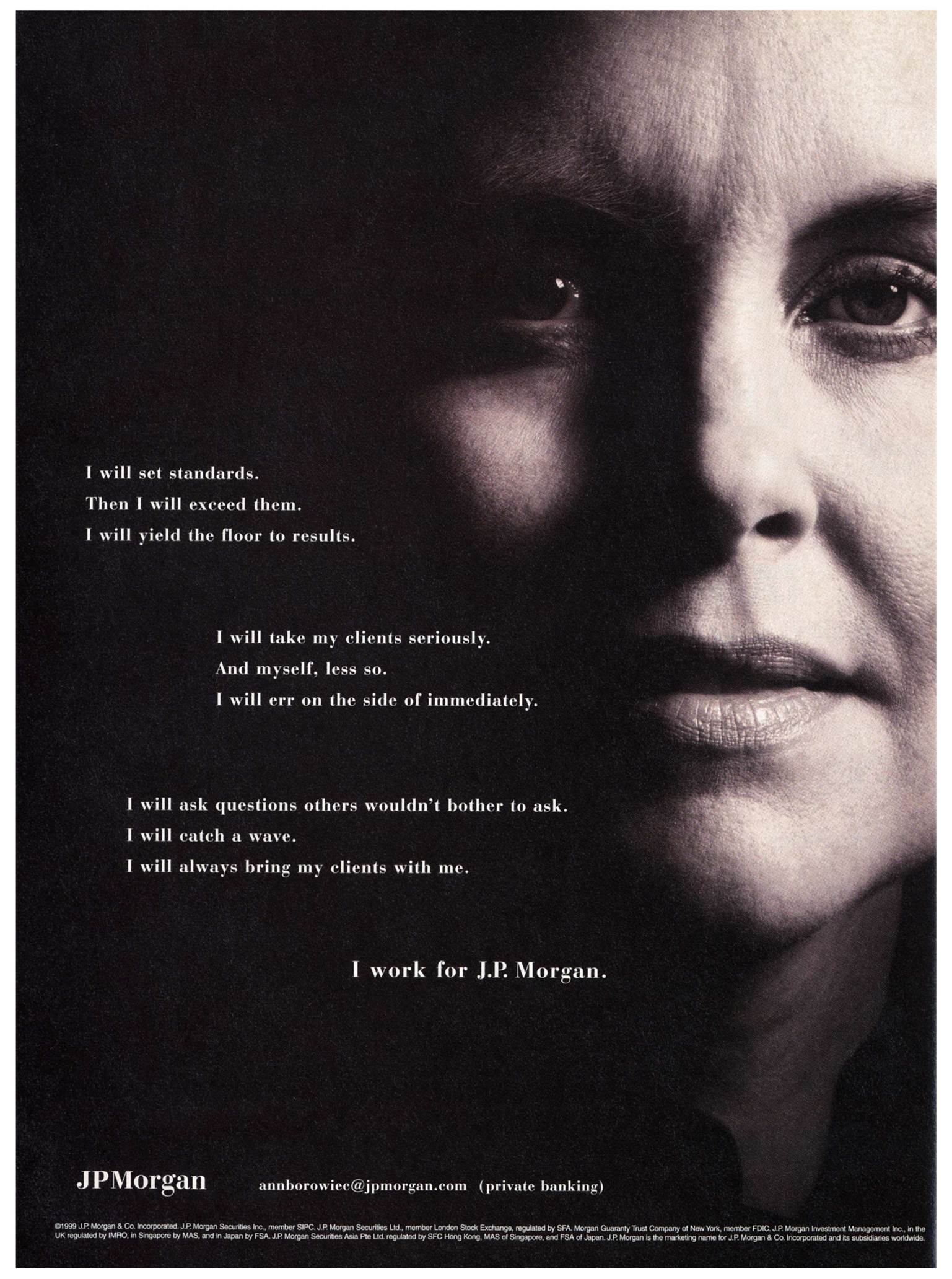
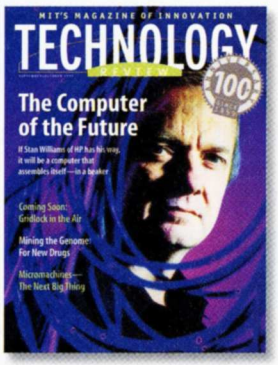


"I think Stan Williams did a brilliant job of assessing the future trends and technological hurdles ahead for silicon electronics."

Kick-Butt Cool

THE Q&A WITH STAN WILLIAMS ("Computing After Silicon," *TR* September/October 1999) was first-rate. I think that Stan did a brilliant job of assessing the current state, future trends, and technological and economic hurdles ahead for silicon electronics. I share his enthusiasm that the future of electronics will thrive if we don't get locked into conventional thinking. The long-term goal of the Defense Advanced Research Projects Agency (DARPA) Moletronics program, of which HP and UCLA are a part, is to provide moderate computational power and high-density memory in an extremely small, low-power format ("a Pentium on a pinhead").



Even though there will be immense payoffs in electronics when one goes towards nano, we have to keep our eyes wide open to other opportunities. Here is a simple example: Researchers often believe that carbon nanotubes may see their first major use in electronics applications. There are good reasons to believe this is the case; they can behave like metals or semiconductors, they have good thermal conductivities, et cetera. However, we currently have contracts in place at DARPA with Biosource Inc. and Boston College using aligned carbon nanotubes for desalinization of seawater, of all things! Within the next few months we'll know how well this works. The tubes offer much promise for desalinization—low-power, inexpensive manufacturing, smaller footprint. It will be kick-butt cool.

BILL WARREN
DARPA
Arlington, VA

THERE ARE MANUFACTURING LIMITS beyond which today's methods for making computer chips just can't go. To beat those limits, we need new methods and new approaches that are molecular in precision. The work by Stan Williams and others at HP and elsewhere is part of a new and rapidly growing wave of research into post-lithographic manufacturing methods. Research into self-assembly and positional assembly will let us make the molecular logic elements and systems of tomorrow. Companies can either join in, or risk the fate of the vacuum tube makers of the 1950s.

RALPH C. MERKLE
Research Scientist
Xerox PARC
Palo Alto, CA

IT IS ENCOURAGING TO SEE your recent article highlighting the emerging field of molecular-scale electronics. The maturation of silicon technology and the need to develop alternatives has long been recognized (see, for example, R.W. Keyes, "What Makes a Good Computer Device?" *Science,* 11 October 1985, p. 138, or R.T. Bate, "The Quantum-Effect Device—Tomorrow's Transistor," *Scientific American,* March 1988, p. 96), although only recently with appropriate seriousness, perhaps due to the realization that the end of Moore's Law will happen not after one's retirement, but within their career lifetime. A contemporary perspective by leaders of industry and academia on the end of the silicon roadmap is given in *Future Trends in Microelectronics: The Road Ahead,* S. Luryi, J. Zu, and A. Zaslavsky, eds. (Wiley, 1999), the proceedings of the conference "Future Trends in Microelectronics," Isle de Embiez, France, 1998.

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E-mail: <letters@techreview.com>.
Please include your address, telephone number, and e-mail address.
Letters may be edited for clarity and length.

As we watch these new technologies develop, we should remember that futurists of the 1950s would have overwhelmingly predicted a nuclear-powered waffle maker over a personal computer. The eventual impact of molecular-scale electronic systems may be significantly different than straightforward extrapolations of today's computing paradigm. Although reticent to make predictions of the technology, I am confident in one—whatever predictions we make, they will be far too conservative.

MARK REED
Department of Electrical Engineering
Yale University
New Haven, CT

Slow Down!

THE ARTICLE "MINING THE GENOME" (*TR* September/October 1999) revealed, perhaps unwittingly, the kind of hubris that can lead to disaster. I refer to such expressions as "genetic noise" and "irrelevant code." To dismiss millions of years of evolution implies a lack of respect for the complexity of nature.

Years ago, early in my medical training, we were taught that the spleen "did nothing," and surgical removal was routine for any splenic injury. As our understanding of this organ's role in the immune system grew, so did efforts to develop spleen-saving strategies, and now the spleen is rarely removed.

Those who are mining the genome in a blind utilitarian fashion may well create the kinds of crises that we face due to the fallout of other technological advances, from burning oil to splitting the atom. Nature does not waste space, or genetic code. We are becoming arrogant and dangerous just because we've developed some basic comprehension and manipulative skill. Those noisy or irrelevant parts may well be the key to the controls and context of the power of genes. My advice: slow down.

DAN K. MORHAIM
Owings Mills, MD

Hubbub and Spoke

THE MAJOR REASON THAT WE ARE NOW encountering so many "Delayed Takeoffs" (*TR* September/October 1999) is that the airlines are scheduling more arrivals and departures than most airports can handle. GPS has really opened the door for more free flight between departure and

arrival points, but all these arrivals must be sequenced to the destination airport to ensure that we don't have two aircraft trying to land at the same time.

Reducing final separation won't work, because we have to have the guy in front off the runway before the guy coming up his tailpipe lands. The best thing the industry can do is start building larger airports, with true parallels where we can run simultaneous approaches.

MICHAEL RAMSEY
National Air Traffic Controllers Association
Fort Wayne, IN

THE CONCEPT OF FREE FLIGHT AS described in Eric Scigliano's article would resolve only one aspect of improving air transport service. It would provide faster and more efficient traffic flow but would do nothing to relieve congestion at major airports. Some years ago, when the passenger air transport system was just becoming significant, an executive at one of the railroad companies commented that the design of the airports and air routes was backwards. He noted that the airlines had many routes all over the country that were terminating at airports with only one or two operating runways. He compared this to the railroads, which connect cities by only one or two tracks but have many tracks at the terminal. Trains are rarely held up outside the terminal waiting for a clear track to an empty platform.

It would be impractical to build airports with dozens of parallel runways. But to fully benefit from free flight, the current hub-and-spoke route system should be greatly revised to eliminate the major hubs with their congestion and substitute many small hub airports where rapid plane changes could be accomplished and where through flights would need to spend minimal time on the ground.

MARTIN A. SNYDER
Concord, CA

ERIC SCIGLIANO'S "DELAYED TAKEOFF" overlooked the main reason for delaying takeoffs—airport congestion. Hub-and-spoke operations by the airlines have led to an increase in smaller aircraft (as cited in the article) and have clogged hub airports causing large delays. Hub airlines want as many arrivals as possible in a short period followed by a similar rush of departures. Flying from Los Angeles to Chicago to meet one of these rushes will necessarily mean that a flight will be delayed en route or as it approaches the terminal, because of our inability to predict flight time accurately.

While a conflict probe and arrival sequencer may help controllers prepare the Chicago arrival traffic stream, these tools rely on accurate flight-time predictions and coordinated information between the automation systems. Both of these underlying technologies need work. A few years ago I observed an arrival flight pattern that caused a continuous 45-minute delay on aircraft approaching a hub location. If our ability to predict flight times were improved, this delay could have been reduced. Discussions with the author might have provided the MIT community the opportunity to introduce more of these systems engineering implications into an article about how to evolve our nation's air traffic system to handle projected growth efficiently.

MARK HANSON
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Concord, MA

Shocking Power

I AGREE WITH MICHAEL DERTOUZOS THAT privacy is not doomed ("Privacy Is Not Doomed," *TR* September/October 1999). However, I do not agree with Dertouzos' assumption that the only way to solve this problem is through the use of government mandate. Part of the problem is that the government (in the United States, at least) is standing in the way of the widespread use of strong encryption over the Internet. The argument for the need of governments to have access to people's records to catch criminals sounds good, but doesn't stand up to the facts. One example, not entirely related to the Internet but relevant nonetheless, is the law in the U.S. called the "Banking Secrecy Act" which actually does the reverse, giving the government complete access to all banking records. Although this law has given the government access to more than 235 million people's private interactions for more than 20 years, fewer than 500 people have been convicted as a result. The law results in far more damage to society, due to lost privacy, than the criminals have caused.

Dertouzos' expression of shock at the statement, "go figure out a solution to the privacy problems you brought upon us!" is entirely relevant, but for the wrong reason. It is shocking that someone with political power would put aside the opportunity to garner more power by implementing a solution, whether it works or not, just to show they are "doing something." My suggestion to the technology industry is—take the ball and run with it!

JONATHAN JOSEPH LEE
Blytheville, AR

Cynical Tirade?

ONE FACET OF THE FUTURE OF BUSINESS omitted from G. Pascal Zachary's column "Net? Nyet!" (*TR* September/October 1999) may change all business drastically—putting many, if not most, retailers out of business! When manufacturers now selling through retail outlets realize that the 40 percent markup that the retailers apply can be added to their own bottom line, they will quickly open or enlarge their direct contact or catalog outlets and bypass retailers not under their control.

SEYMOUR TAYLOR
New York, NY

TO G. PASCAL ZACHARY: I READ YOUR COLumn with amusement this morning. I have a couple of friends who would most definitely agree with you—they, like yourself, think this whole Internet thing is all hype and can't stand to hear about the big trend, let alone all the people getting rich. I suspect that you also have something else in common with my friends: You missed the boat, and sat on the sidelines while Net stocks went up and up and, having missed out on the whole thing yourself, you've reduced yourself to bitter cynical tirades about how it's all a sham and will evaporate someday.

Net stock valuations are high, but not nearly as unjustified as you seem to think. Your examples in the article are all business-to-consumer; these are the ones that get all the hype. But for every profitless retail.com out there, there are 10 companies using the Net to truly re-invent business, by forging supplier linkages and other innovative uses of the Internet.

As for the "rich will get richer" theory—in some cases that is true, but not in others. eTrade and Ameritrade have fundamentally changed the way brokerages work—do you really think Merrill Lynch (whom you cite) will ever catch up in online brokerage? To several generations of new and budding investors, Merrill Lynch's name means nothing. I cannot imagine ever giving my business to a bro-

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kerage who until just recently denied that the Net was an important part of their strategy and suggested their customers were not interested in online trading.

ROY M. SCHUSTER
Consulting Manager
Lante Corporation
Chicago, IL

Forest and TRIZ

I WAS A BIT SURPRISED THAT THE ARTICLE on Valery Tsourikov's Invention Machine ("Genius Minus Perspiration," *TR* September/October 1999) made no mention of the Theory of Inventive Problem Solving, an approach to discovering new design concepts which has been around for some time. The process is known by its Russian acronym, TRIZ. In 1946 a Russian engineer, Genrich Altshuller, led a team of analysts to investigate the possibility of discovering domain-independent inventiveness. They researched 400,000 patent descriptions and constructed a logical means to discover new ideas from the interrelated attributes of different areas of expertise. Modern TRIZ has included more than 1,500,000 patents in updating Altshuller's original process. I don't mean to belittle Tsourikov's accomplishments, but I am pretty certain that a group of engineers using TRIZ as their process would easily outshine a computer program that does not appear to be much more than TRIZ programs available today.

DAVID H. LAIZURE
Centreville, VA

Match Point

I ENJOYED YOUR ARTICLE ABOUT JOHN Walker and his 1826 "friction lights" ("Got a Light?" *TR* September/October 1999). However, when I mentioned this to my wife who works at Monticello, she said that Thomas Jefferson had "phosphoretic matches" in 1784. He bought these by the dozen in Paris and when he wrote about them to a friend Charles Thompson in America, he was informed by Thompson that these were sold in toy shops in Philadelphia. See *Thomas Jefferson: Statesman of Science* (Macmillan, 1990) by Silvio Bedini, former Smithsonian curator.

LARRY Z. GOSS AND BETTY L. GOSS
Charlottesville, VA

The editors respond: Mrs. Goss is quite right—Jefferson and other well-to-do citizens of the eighteenth century did have

access to "phosphoretic matches." These were very different, however, from the friction matches we're familiar with. They consisted of a phosphorus-dipped wax taper enclosed in a small glass tube. When the user broke the glass, the taper made contact with the air and flared—at significant risk to fingers and clothing. In a letter to James Madison, Jefferson wrote: "Great care must be taken in extracting the taper that none of the phosphorus drops on your hand, because it is inextinguishable and will therefore burn to the bone if there be matter enough."

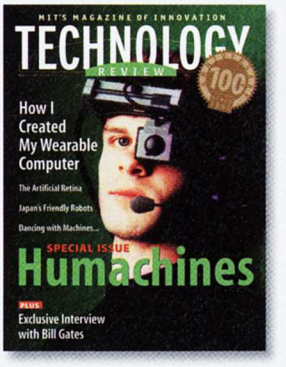
The "matches" of the sort Jefferson found in Paris never really caught on—they were too expensive and dangerous for widespread use. Walker's friction match, on the other hand, was cheap and relatively safe, and lit the way toward near-global access to instant ignition.

Cyborg Controversy

STEVE MANN'S ARTICLE, "CYBORG SEEKS Community" (*TR* May/June 1999) and seemingly corroborating columns misleadingly imply that Mann is the initiator of many of the concepts and communities associated with wearable computing. In fact, wearable computing has a very long history with many contributors (see a timeline online at www.media.mit.edu/wearables/timeline.html).

Mann complains about his loneliness during his years at MIT as "the only wearable computer user." But Mann ignores the MIT Wearable Computing Project, which made much of his work possible. This group effort was initiated and maintained by graduate and undergraduate students interested in the technology, its potential uses and its social effects. While Mann was an early member, he is not considered the initiator of wearable computing research at the Media Laboratory. His apparatus was not commonly known or in evidence at the laboratory until late 1994, when he began to wear a system for transmitting analog video from a headset back to the laboratory for digitization and placement on the Web. In 1995, Mann began to wear what would be commonly considered a wearable computer, even though the designs were based on various laptops. He did not switch to the more compact PC/104 architecture until 1996. In contrast, one of us (Thad Starner), then a fellow graduate student, had been wearing an everyday-use, PC/104-based wearable computer since mid-1993 and gave many public demonstrations of it. Prior to this, members of the MIT community had been exploring the concepts of wearable computing since at least 1989, and functional prototypes by Edward O. Thorp and Claude Shannon date back to the early 1960s.

Furthermore, while Mann may have done significant work using computers to control his photography equipment before coming to MIT, he waited until 1997 to unveil his WearComp0 to WearComp7 progression of machines in his writings. "Mediated Reality," Mann's first writings on wearable computing at the laboratory, appeared in late 1995 alongside "Augmented Reality Through Wearable Computing," a broad summary paper by many authors involved in the project, including Mann. In contrast, Starner's popular press paper, "Cyborgs Are Coming," which addressed the early goals and intentions of the wearables project, was already widely disseminated in 1994 and distributed internally in late 1993. These facts, in addition to the formation of the world-reaching community resources of the wearables research mailing list in early 1994 and the MIT Wearable Computing Web Site in 1995, makes one wonder why Mann bemoans such a lack of community.



Mann's claim to having started the International Symposium on Wearable Computers (ISWC) is similarly misleading. Initial planning began with Dan Siewiorek, Len Bass and Thad Starner in January 1996. Siewiorek and Bass had been teaching exploratory classes in the design of wearable computers since 1991 at Carnegie Mellon University and were very receptive to the creation of a conference to share their work. Mann, whose main focus was photography and video, joined the organizing committee as publications chair in August 1996. Mann's overstatement of his involvement is shown in his overestimation of attendance by a factor of two. ISWC '97 had 382 registrants with an additional 20 members of the press, and the accompanying Media Laboratory wearables event to which he refers drew a little under 1,400 participants. A copy of the original of this letter will be placed at http://www.media.mit.edu/wearables/letter.html.

SUMIT BASU, RICHARD W. DEVAUL, LEN GIAMBRONE, LARRY NAJJAR, NURIA OLIVER, REHMI POST, BRADLEY RHODES, KENNETH RUSSELL, NITIN SAWHNEY, ALEXANDER SHERSTINSKY, FLAVIA SPARACINO, THAD STARNER, JOSHUA WEAVER, CHRIS WREN

(The writers are past and present student members and affiliates of wearable computing projects at the MIT Media Laboratory and Georgia Tech.)

Steve Mann responds:

According to Alex Pentland, academic head of the MIT Media Lab, the MIT Wearable Computing Project began in 1992 as the "Smart Clothing" project. At that time, I was the only one at MIT with a wearable computer. In 1992 I also shot and widely exhibited a number of pictures around MIT using my "phototborg" techniques. Nicholas Negroponte, the Director of the Media Lab, has stated publicly that I was the one who "brought the seed" of wearable computing to the Media Lab. This all happened before Thad Starner (who I know is the actual author of the letter above, despite the others who co-signed it) had a wearable computer of any kind. It was not until 1993 that Starner would have someone build his first wearable computer for him—a system that, unlike the ones I had built myself earlier, had no wireless connectivity and no photographic or imaging capability.

Prior to Starner's involvement, I was a walking television station, video production facility and photographic lighting studio—all before there was any formal notion of an MIT Wearable Computing Project. I typically wore several computers, including one to insert my callsign (N1NLF) into the reality stream I was sending, one to manage my full-duplexing, remote control of the microwave links I had installed on the rooftops of various buildings, and one that served as a video switcher. I often wore more than a dozen computers to control my wearable lighting gear alone. (Some at MIT will no doubt remember the flashes of light from my old computer-controlled wearable photographic gear as I walked around late at

night, "painting with light vectors.") The MIT Wearable Computing Web site of 1995 originated from my 1994 Web page on wearable personal imaging systems and smart clothing.

Starner's claim that wearable computing dates back to the 1960s rests on a very broad definition of "computing." Thorp's device was an analog timer built into a shoe; it was no more a computer than a stopwatch is. The Web-based timeline mentioned in their letter attempts to suggest that wearable computers have been around for centuries by citing such devices as eyeglasses and wristwatches. But none of these everyday items is a computer. For example, to change the behavior of eyeglasses, you must regrind the glass or melt down the plastic. What makes computers unique and compelling is that they can be reprogrammed to do a variety of very different tasks. (See www.wearcomp.org/wearhist.htm for a peer-reviewed and commonly accepted definition of wearable computing.)

Starner and I had discussed, for a number of years, my idea of having a conference on wearable computing; it was I who made the first contact with the IEEE. As to the head count, the actual attendance at the October 1997 conference was far greater than official registration would indicate. There were a tremendous number of nonregistered attendees, including spillover from the opening of a public exhibit of my early wearables at the Media Lab's List Visual Arts Center (see www.wearcam.org/lvac/index.html). My work on personal cybernetics has appeared in peer-reviewed scientific literature. See, for example, "Humanistic Intelligence: WearComp as a New Framework for Intelligent Signal Processing," in the November 1998 *Proceedings of the IEEE,* and others at www.wearcam.org/wearpubs.htm.

CORRECTIONS:

In "Rewriting the Bible in 0's and 1's" (*TR* September/October 1999), Donald Knuth's Web address was given incorrectly. The correct URL is http://www-cs-faculty.stanford.edu/~ knuth/.

Rosetta Inpharmatics of Kirkland,Wash., should have been credited as the source for the illustration that appeared on pp. 62-63 of "Mining the Genome" (*TR* September/October 1999).

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Feel the Pressure

In the real world, shooting a gun bears little resemblance to shooting pool. But in computer games, just about everything—fighting wars, flying planes, playing sports—is reduced to twitches of the hand and arm, communicated through the omnipresent joystick. Miacomet, a Springfield, Mass.-based startup, intends to change that. The company's first product, a pool-game interface, consists of a U-shaped structure that accommodates an ordinary pool cue. A mechanism similar to the one in a computer mouse senses the cue's motion; the faster you move the stick, the harder it "hits" the ball on the PC screen. A force-feedback fishing rod due out early next year uses motion sensors and reduction gears to give the feel of casting a line, getting a nibble, and hauling a big one onto the dock. Miacomet CEO Randy Hujar says that in the next year or so Miacomet will bring out specialized controllers for golf, tennis and baseball, as well as a stand-on platform for snowboarding or skateboarding.

Reading Smoke Signals

A U.S. Army ranger is on a battlefield in a country known to be making chemical weapons. Through his binoculars, he spots a cloud of smoke a mile away. Does it contain lethal gas? At the moment, there is no easy way to know. But researchers at Sandia National Laboratories and MIT are working on a dime-sized sensor that could be built into binoculars or telescopes to spot toxic gases before they do any damage.

The sensor identifies the infrared absorption spectrum of a gas. When a toxic gas is picked out, the system alerts the user. The researchers, who include MIT's Steve Senturia and Sandia's Mike Butler and Mike Sinclair, expect to test an experimental device this fall; they hope to build a lab prototype within two years. Although the device is being developed for the military, it carries obvious peacetime uses—fighting chemical fires being one.

Melanoma Monitor


UNIVERSITY OF ROCHESTER

Melanoma, the deadliest form of skin cancer, is curable if you notice it early enough—when a mole on your body first changes in appearance. But that's not so easy if the mole is on your back, or if you have a lot of them.

A "melanoma monitor" being developed at the University of Rochester's Center for Future Health may be able to watch your moles for you. A set of home digital cameras—in the shower, for example—would periodically take pictures of your body. A computer would compare images over time and alert you if it detected a change. Present software can detect changes on a human arm. Rochester computer scientist Kiriakos N. Kutulakos estimates full-body versions could be in doctors' offices in five years, and in the home in 10.

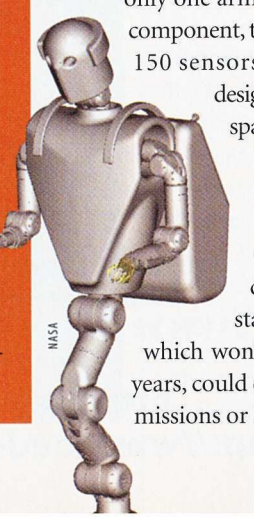
Lightning Scalpel

It's one of the most delicate operations imaginable: An eye surgeon excises a piece of membranous tissue next to a patient's retina that threatens to damage or obscure the light-sensitive cells. Such "vitreoretinal surgery" can save the vision of someone whose eyes have been damaged by diabetes or trauma, but conventional microblades and microscissors can tear fragile tissues, and attempts to use lasers haven't succeeded. Researchers at Stanford believe they've developed a better option—a needle-sized "plasma knife" that cuts via blasts of electricity.

The new knife, explains Stanford physicist Daniel Palanker, is a tiny electrode that delivers electrical pulses a few nanoseconds long to create "plasma streamers"—lightning-like discharges that slice through soft wet tissues. Since the process doesn't require traction, as cutting with blades does, the risk of tearing is reduced. The surgeon sets the cutting depth and speed by adjusting pulse strength and duration. Mark Blumenkranz, chair of the department of ophthalmology at Stanford University School of Medicine, is helping test the plasma knife on rabbits; the researchers hope to begin human trials by year's end. Eventually, Palanker says, the plasma device could be used not only in vitreoretinal surgery but also to treat conditions such as cataracts and glaucoma.

Space 'Bot

Working in outer space has been compared to climbing a mountain in scuba gear. Tough on astronauts—and dangerous. One solution: Let robots do it. NASA's Johnson Space Center is working on a handy humanoid robot that's designed to live and work in the void. So far, says project leader Robert Ambrose, NASA has built only one arm of the "robonaut." That's the key component, though. Packed with 19 motors and 150 sensors, the arm has dexterous digits designed to grab tools, railings and other space stuff designed for human hands.


NASA

The robonaut's first assignment could be outside the International Space Station, where it would address equipment snafus, remote-controlled by humans inside the station. Ambrose says the robonaut, which won't be space-ready for at least four years, could eventually serve on interplanetary missions or help fix satellites in high orbit.

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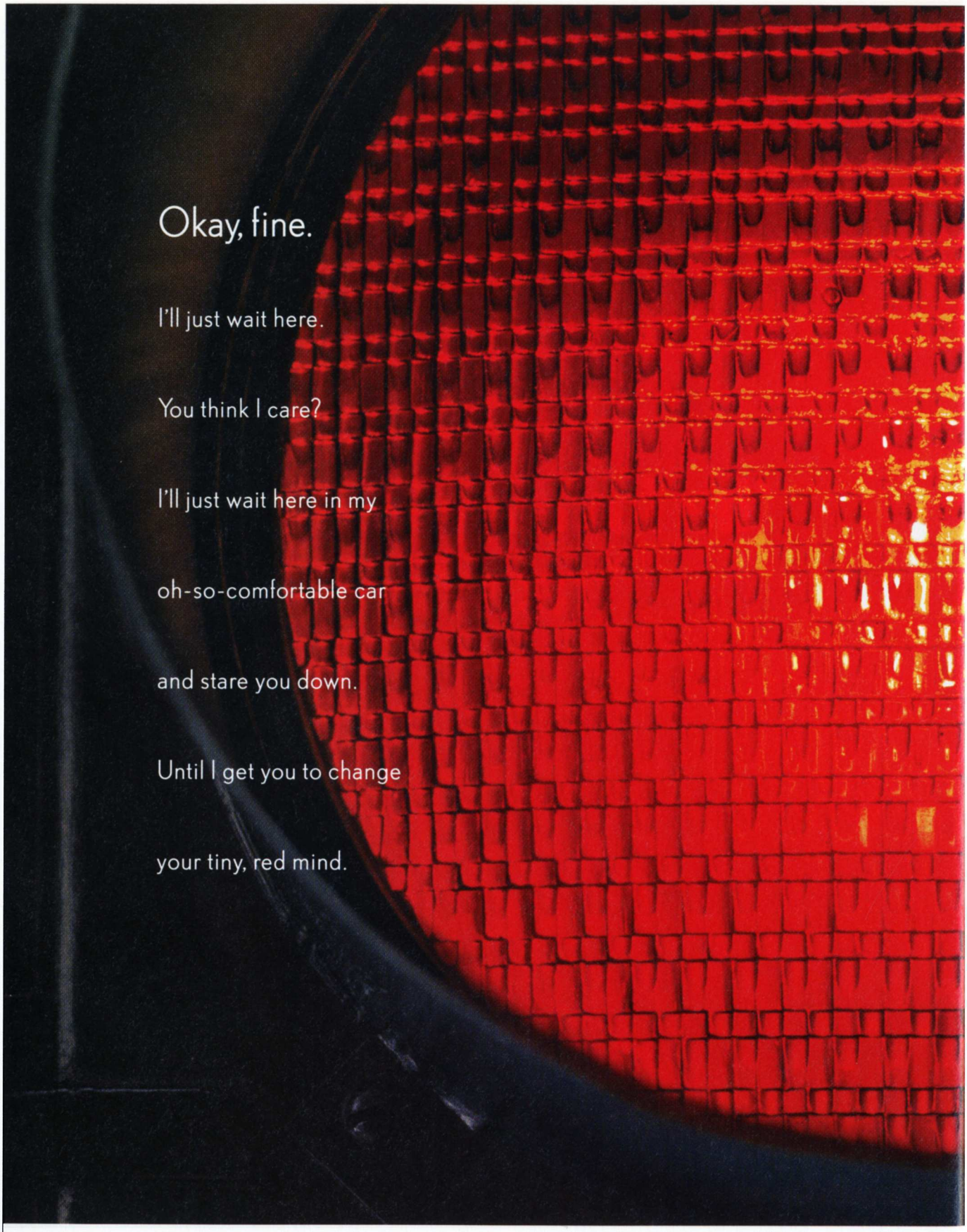

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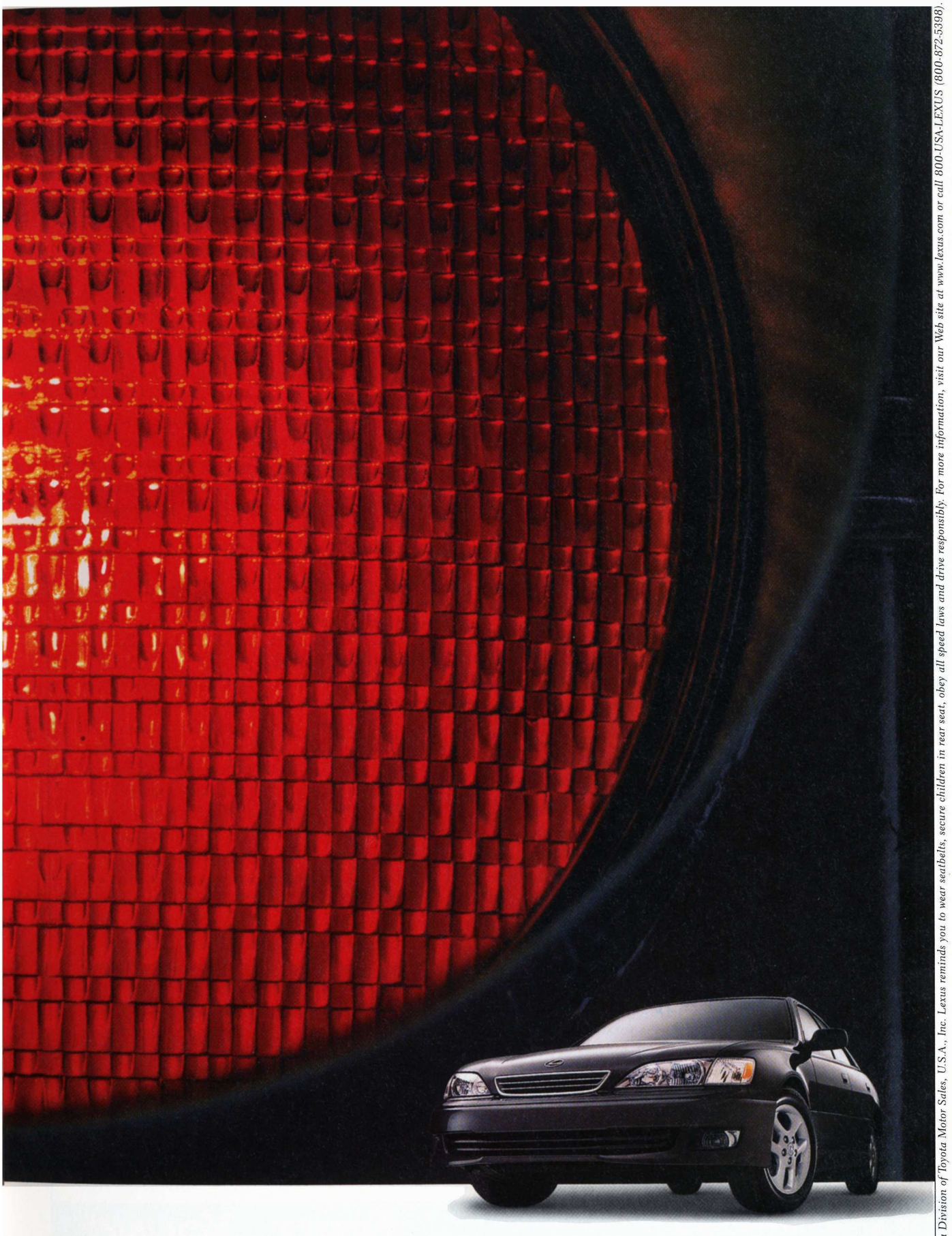

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Four Pillars of Innovation

"How can we become innovative, like MIT, and the startup companies of Route 128 and Silicon Valley?" That's the most frequently asked question I've heard in the last 25 years, as individuals and organizations in Europe and Asia, but also in the United States, strive to get on the bandwagon of high-tech innovation. Thousands of books and magazine articles purport to answer this question. Yet the ones I've seen don't quite match the ingredients I have found to be important among the most successful of the MIT Lab for Computer Science's 60-some startups.

Two ingredients, risk-aware capital and a high-tech infrastructure, are obvious, but rarely in place. In Europe and Asia investors talk about risk, but their psyches propel them toward the comfort of guarantees. They are not prepared to lose 10 startups for a 100-fold appreciation in the one that makes it big. In the United States, where capital is usually risk-aware, it is often greedy and lacks staying power—two additional avenues to failure. And in many regions of the world, there is little infrastructure in the form of silicon foundries, design houses, and the human experts behind them to ensure that a fledgling high-tech company will have quick and easy access to such key resources.

Perhaps the most important ingredient of successful innovation is the creative technological idea that serves a pressing human need. This kind of creativity, in turn, requires a schizophrenic combination of rationality and insanity that's outside our ordinary experience. Imagine that all current inventions in the world and all their possible logical extensions and uses are inside a huge balloon. People are pretty good at extending these ideas further, using logic and common sense. But their results, being logical extensions of what's already there, stay within the balloon. To escape these old ideas and come up with something that is radically new, the balloon must be punctured with something that defies reason—a new idea that is akin to a form of insanity. Yet most insane ideas fail to be creative; they're simply insane. That's why successful innovators, after coming up with an idea that seems crazy, must be able to shift seamlessly to a rational dissection of the idea's merits and pitfalls. When this interplay between insanity and rationality converges, look out! A creative idea has been born.

Conventional marketers and venture capitalists react to creative technological ideas with indignation—"all you have is a solution looking for a problem"—or the mantra—"you better start with a market need, otherwise you have nothing." These phrases play well in the how-to books, but not in my experience: The successful startups I have known began with what we affectionately call a new hack—a radically new technological idea—like the Ethernet (3Com), the spreadsheet (Lotus) and public key cryptography (RSA). Sure, a market story is always there, next to the technical idea, but at the beginning, the market is often incorrectly identified: When we invented time-shared computers, we did it to distribute the cost of a million-dollar processor among many users. Today, with powerful processors at a few hundred dollars, banks and airlines use this technology for a totally different reason—to share information. The Arpanet, too, was invented to keep costs down by enabling Defense Advanced Research Projects Agency contractors to do their computing on each other's machines. Nobody did that. Instead, the new networking capability gave rise to e-mail, file transfers and, eventually, the Internet. In short, the debates on whether the market or technology should lead innovation are irrelevant: Successful innovators apply their drive and flexibility toward looking for and blending these two forces wherever they crop up, always striving to zero in on the key ingredient—a creative idea that serves a pressing human need.

People think entrepreneurs start companies to make big money. Not the ones I know. They're motivated by passion.

The other important ingredient of innovation in my experience is an entrepreneurial culture centered on passion: Besides being expert in their craft, the winners are believers, committed unconditionally to their creative idea. To understand how important passion is to innovation, look at "technology transfer" through inanimate designs: In my experience, the people who are handed someone else's invention have no stake in it; sooner or later they find an excuse to abandon it. People think entrepreneurs start companies to make big money. Not the ones I know: They do it first for passion, and only then for money. And where there is no passion, there is usually no money. The right entrepreneurial culture, too, requires a strong leader, who fuels passion and keeps everyone focused on the main mission. And when they fail, the best innovators are ready to move on to their next startup without a second thought.

All four ingredients—risk-aware capital, a high-tech infrastructure, a creative idea that serves a pressing human need, and a passion-oriented entrepreneurial culture—are rare. It's even rarer for them all to come together in a startup. Perhaps that's why so few succeed. But when they do, the rewards are ample: Entrepreneurs derive satisfaction in translating their dreams to useful products and services. They and others become wealthy. And the siren song gets louder, beckoning more newcomers to the seductive promise of innovation.

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CORPORATE STRATEGY

Venturing Out

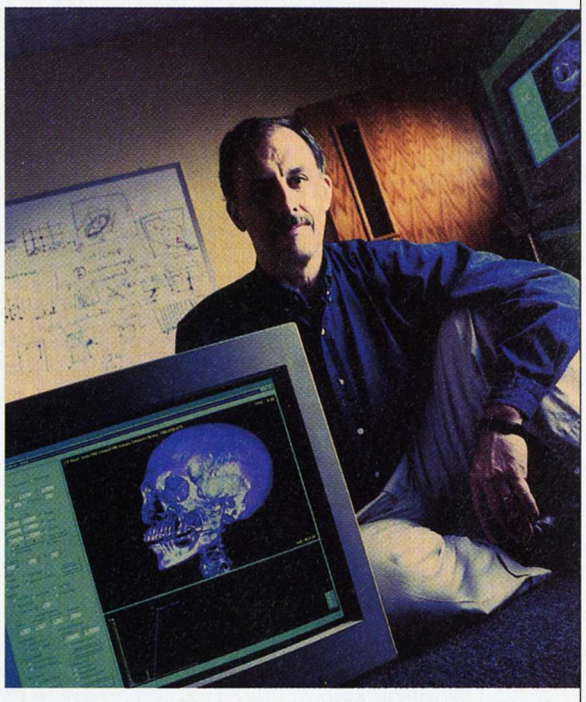
Mitsubishi tests the entrepreneurial waters

SITUATED IN THE TONY BOSTON SUBurbs popular with high-tech firms, the operation might be any startup. Wide-eyed engineers tap feverishly on keyboards, while around them the facilities are still being built. It would be business as usual in the world of startups, except for the name on the front door: Mitsubishi Electric.

It's an experiment in entrepreneurship American-style—the first for the giant Japanese corporation. Mitsubishi has taken a technology developed at its research lab in Cambridge, Mass., and is attempting to build it into a business, Real Time Visualization. Though wholly owned by Mitsubishi, the outfit runs like a venture-backed startup. This summer the fledgling company made a big splash with the introduction of a computer-graphics first: a product that constructs 3-dimensional images in real time (30 frames per second) using a single custom-designed chip. It uses a type of 3-D graphics, called volume rendering, that has until now been possible only with software running on a powerful workstation or a supercomputer costing tens of thousands of dollars. Real Time Visualization puts its special-purpose chip on a standard PC board that computer system makers can buy for $3,000 to $5,000.

Lots of computer graphics give a 3-D illusion. But peer behind the facade and you come up empty; the computer model typically has no information about the internal structure of the objects it displays so realistically. Volume rendering is different; it displays objects as assemblages of 3-D chunks (called voxels, for volume elements). A volume-rendered representation can be sliced open and examined much as you would a physical object.

One of the biggest expected applications is medical imaging. The technology makes it possible to produce images of the heart and brain that can be inspected on screen from all angles. Another market should open up soon: Beginning in 2001, federal regulations will require inspection of every piece of luggage checked onboard an airplane (not just carry-ons). A volume rendering computer system will help to examine suspicious bags without opening them.



WEBB CHAPPELL

New chip gives real-time 3-D graphics on a PC, says James Jacobs.

For now, Mitsubishi is giving Real Time Visualization a long leash. "There's no control from Japan," says Steve Sandy, director of business development. General Manager James P. Jacobs reports to a board of directors, much as the CEO of a venture-funded startup would. According to Jacobs, Mitsubishi has allowed the business more freedom than Japanese companies usually permit their divisions. But with independence comes risk. Mitsubishi will fund the operation through 2000, Jacobs says; after that, he projects that sales will make the outfit self-sustaining. If they don't, he doesn't expect to go back to the mother ship for more subsidies. "We'll seek outside investment," says Jacobs—just like any other U.S. startup.

Although it's the first venture of its kind for Mitsubishi, it probably won't be the last. Sandy says the corporate giant is already looking into spinning off outfits to chase high-tech markets in software and Internet telephony.

—Herb Brody

VENTURE CAPITAL

Bucks Start Here

Venture capitalists have been investing enormous sums—$7 billion in 1998 alone, much of it into new Internet and telecommunications companies. Will these heady days for startups continue? Yes, almost inevitably, say experts, citing two and a half years of record-breaking fundraising by leading venture capital firms. According to market research firm VentureOne, venture funds this year are set to meet or exceed 1998 levels, when they collected $15.7 billion from limited partners (the corporations, pension funds and wealthy individuals whose money they invest). That was more than double the 1996 figure of $7.7 billion.

"There is a considerable pent-up pipeline of investment money," says PricewaterhouseCoopers analyst Larry Buchsman. Because it typically takes several years to spend a newly raised fund, the effects of surging commitments to venture funds that began in 1997 are starting to be felt as venture firms channel these windfalls into startup companies. Says Paul Zigman, a partner at Ampersand Ventures of Wellesley, Mass.: "It's a good time for entrepreneurs." **—Antonio Regalado**

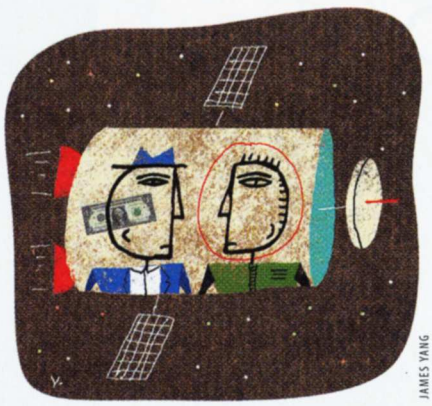
SPACE EXPLORATION

View From the (Very) Top

NASA looks to sell real estate on the space station

FOR SALE: CONDO, GREAT VIEW, MANagement on premises, can be used for business or retail space, price negotiable. An ad like that might draw a rush of buyers in New York or San Francisco, but NASA is finding out that it's not exactly a seller's market when it comes to hawking room on the international space station (ISS).

At NASA's Habitation Module Commercialization Conference this summer, the space agency floated the possibility that one or more commercial partners would own and maintain the crew habitation module—essentially the living quarters—on the space station. NASA would lease space. While the government has previously leased privately owned assets on communications satellites, there has never been corporate ownership on manned space vehicles. However, the ISS is likely to be different. In fact, the Canadian Space Agency has already turned over allotted experimental space on the station to an American company, SPACEHAB.



JAMES YANG

Construction of the space station is scheduled to begin next year, and work on the module is over budget and behind schedule. Part of the problem with the living quarters is that NASA wants to replace a proposed aluminum cylinder with an inflatable module that has three times the volume. But last year Congress nixed the idea. To build the module, NASA needs to find at least $200 million.

The agency's sales pitch goes something like this. Think of the possibilities: You could lease living space to government users and, someday, tourists. Profitable experiments and manufacturing in space may finally materialize in the next few years, and eager entrepreneurs will surely be banging on the space station's hatchway looking for room. What's more, you could lease the module for filming of advertising and even movies.

Some potential buyers, though, are not sold. Attendees at this summer's conference questioned, among other things, NASA's willingness to give up even partial control of its pet project. "If NASA wants a sincere dialogue, it must be as a customer and not as an owner," says Robert Bigelow, an investor at the conference.

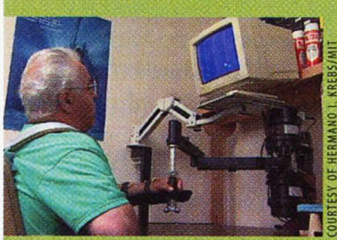
But NASA is committed to making ISS attractive to businesses. Says NASA's Dan Tam, "On Earth, it has been demonstrated time and time again that with market support, private industry can do a better job than the government. We expect the same will be true in space."

—James Oberg

PHYSICAL THERAPY

Robotic Road to Recovery

Americans suffer three-quarters of a million strokes every year. For those who survive, recovery can be long and arduous. It doesn't help that rehabilitation techniques are, for the most part, still remarkably low-tech. Therapists typically exercise patients' impaired limbs using repetitive hands-on maneuvers and mark improvements on clipboards. Because it's labor-intensive, the process is also expensive. Indeed, the annual price tag for the U.S. economy of stroke treatment is $30 billion and will likely escalate as Baby Boomers reach the peak stroke ages and drugs improve survival rates.



COURTESY OF HERMANO I. KREBS/MIT

A stroke patient uses a robot and video game for rehabilitation.

One solution: robots to boost the effectiveness and productivity of rehab. Systems designed by Neville Hogan and Hermano I. Krebs of MIT simultaneously deliver therapy and measure recovery of limb control. Playing specifically designed video games, the patient maneuvers the robot's mechanical arm horizontally, moving it like an oversized computer mouse to work the wrists, elbows and forearms at graded levels of resistance. A computer records the robot arm's position, velocity and the force the patient exerts.

Hogan and Krebs developed their devices at MIT's Newman Laboratory for Biomechanics and Human Rehabilitation. They have tested them at the Burke Rehabilitation Center in White Plains, N.Y. Those tests, including a recently completed trial involving 60 stroke victims, show that, on average, patients receiving robotic therapy regained control of their shoulders and elbows at twice the rate of those limited to standard therapy. "These results are encouraging," says Larry Goldstein, head of the Stroke Policy Program at Duke University Medical Center. "There appears to be some improvement of stroke-related impairments that is long lasting."

Hogan envisions a clinician working a room full of robot-assisted inpatients, or even demonstrating exercises online and monitoring patients at home who are rigged with robot and modem. The MIT scientists are fine-tuning the system and devising new versions to work with legs and move in three dimensions. Says Krebs: "Our work opens up a vast area of research not only for us, but also for other groups to develop new tools to be used in stroke rehabilitation."

—Mark Dwortzan

Will you be a leader in the New Economy?

Who did *The American Lawyer* find to be the nation's top-rated law firm by New Economy companies?

FIRMS MENTIONED MOST OFTEN

1. Brobeck, Phleger & Harrison
2. Wilson Sonsini Goodrich & Rosati
3. Cooley Godward
4. Fenwick & West
5. Gibson, Dunn & Crutcher
6. King & Spalding
6. Orrick, Herrington & Sutcliffe
8. Hale and Dorr
8. Morrison & Foerster
8. Skadden, Arps, Slate, Meagher & Flom

FIRMS MENTIONED MOST OFTEN AS CORPORATE COUNSEL

1. Brobeck, Phleger & Harrison
1. Hale and Dorr
3. Davis Polk & Wardell
3. Gibson, Dunn & Crutcher
3. Skadden, Arps, Slate, Meagher & Flom
3. Venture Law Group
3. Wilson Sonsini Goodrich & Rosati

FIRMS MENTIONED MOST OFTEN AS LITIGATION COUNSEL

1. Brobeck, Phleger & Harrison
2. Orrick, Herrington & Sutcliffe

FIRMS MENTIONED MOST OFTEN AS SECURITIES COUNSEL

1. Brobeck, Phleger & Harrison
1. Wilson Sonsini Goodrich & Rosati
3. Gibson, Dunn & Crutcher
3. Willkie Farr & Gallagher

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(Duplicate numbers indicate a tie in the ratings)

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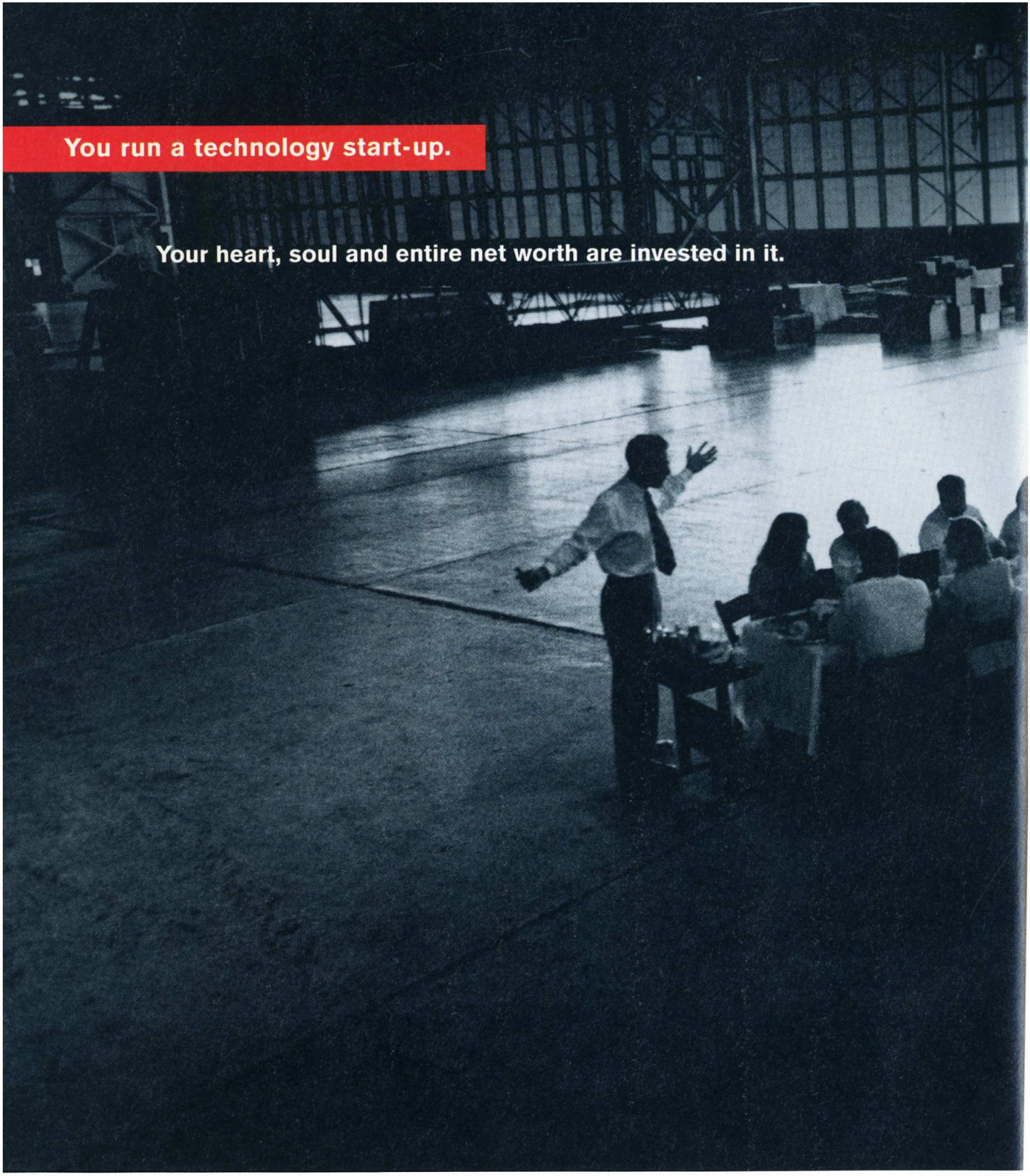

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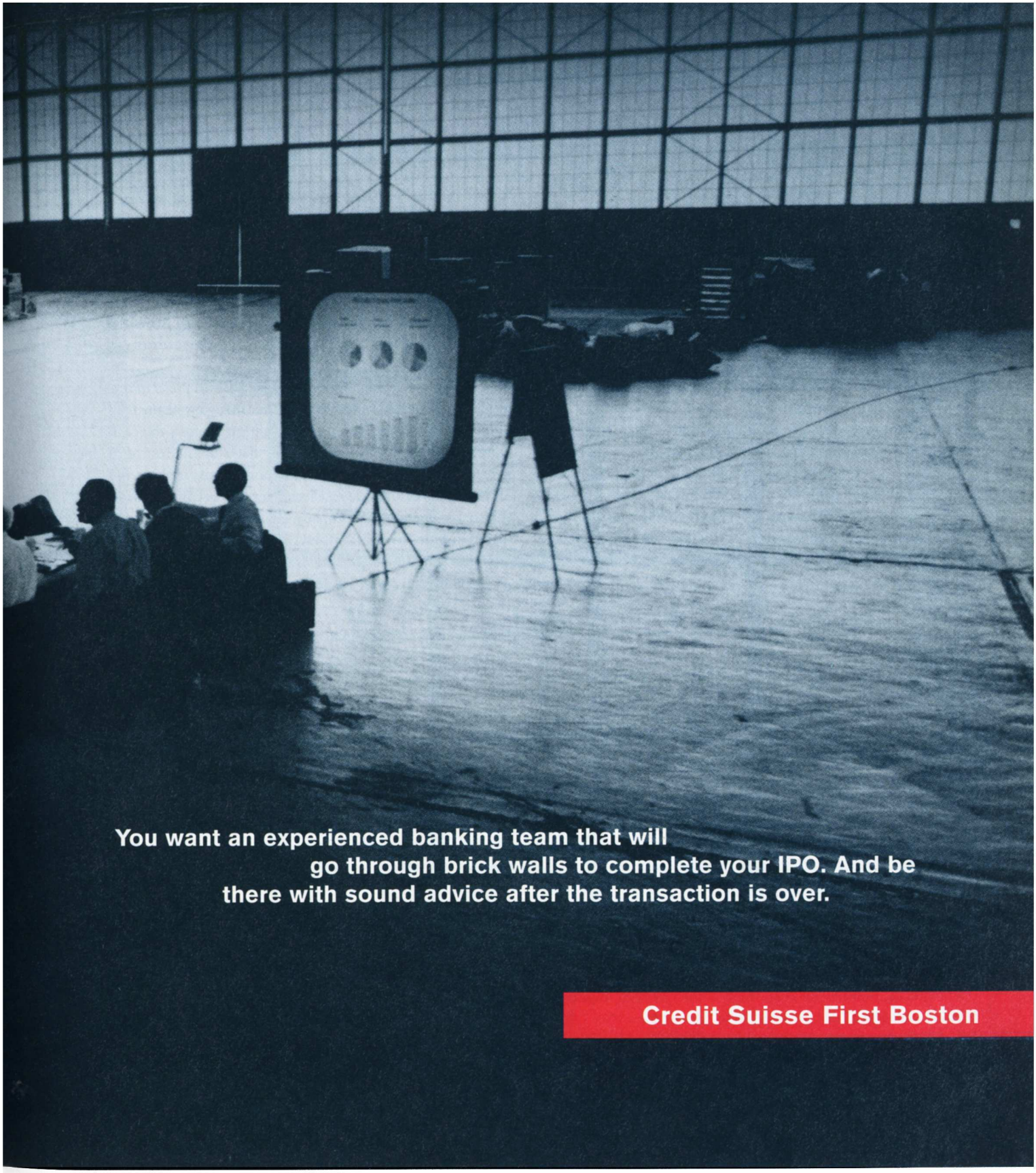

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The Intel Octopus

REMEMBER THE OCTOPUS? NEARLY A CENTURY ago, novelist Frank Norris came up with that image to refer to big businesses that, through cross-ownership agreements, gained effective control of whole industries. But the term isn't just a musty reminder of the age of J.P. Morgan. It's highly relevant today, in the highest of high-tech sectors—computing.

Is Intel the "Octopus" of the Information Age? Or has the world's most profitable manufacturer simply found a better way to sponsor innovation?

These are the key questions about Intel's audacious program—of unprecedented scale in the history of American business—to invest hundreds of millions of dollars each year in scores of small companies based on hot new technologies. In the past three years alone, Intel has invested a cool billion in hundreds of projects around the world. Intel rarely plays a direct role in management and usually invests about $3 million per pop.

Could Intel's wide-ranging venture investments enable it to squelch innovative competition?

But Intel isn't playing Good Samaritan. The company says it hopes the investments will give its own researchers a view of the high-tech horizon and a chance to catch the next great waves of innovation. Intel's CEO, Craig Barrett, says its venture-capital investments can bear more fruit than "putting a group of 50 [Intel] researchers into a building in these spots." The company invests in more than semiconductor technology—including research into the Internet, communications, software and video technology.

As with its industry-leading microprocessors, Intel is a pioneer in this approach. The company is essentially extending the make-or-buy decision to research. Its tactic reflects the belief that doing all of your own research has its drawbacks. Besides the cost, there is the risk that in-house teams develop a "not invented here" syndrome.

That won't happen to Intel, says Stephen Nachtsheim, who oversees the company's investment program. Nachtsheim says the company wants a supplement for its own research and development, not a substitute. He lists four priorities for Intel's investments:

Expand existing markets: Intel wants to support companies that come up with new uses for chips.

Gain new "process" expertise: The ability to make chips, which is growing harder as the chips grow smaller, increasingly distinguishes leading chip concerns from the also-rans. "By investing, we can help companies deliver these process technologies to us faster than they might otherwise," Nachtsheim says.

Find new markets: Intel has grown phenomenally over the past 10 years, but its growth is slowing. It wants to enter hot areas outside chips.

Earn profits: With investors valuing new technology companies at record amounts, Intel expects to post profits on many of its investments. The company won't say how much it's earned so far, but Nachtsheim says that, as of the end of 1998, the 220 companies it had invested in were worth an estimated $2.5 billion.

Intel is in a good position to make shrewd picks in high tech. Its top managers have a commanding view of the technologies converging around information. In fact, the company's expertise raises some danger flags for the rest of us. Like Microsoft, the company is a monopoly. As it places bets on hundreds of outside research teams, it becomes reasonable to ask whether the company will ever try to impede innovation in order to defend its lucrative turf. This is the "Octopus" problem.

Nachtsheim says, "There are no antitrust implications" from Intel's investments—the company never will squelch innovations that threaten to cannibalize its own products. He says the company rarely takes more than a 20 percent stake in a company or puts a representative on the company's board. These are reasonable ways to safeguard innovation against the Octopus. Still, it would help if Intel would name all the companies that it invests in. (It won't, citing the need to keep secrets from rivals.)

Intel is no less honest than any other major company. But honesty isn't the issue, it's influence. Intel is so big and rich that its venture investing creates the possibility for all kinds of conflicts. As its portfolio grows, hundreds, even thousands, of small high-tech innovators will owe Intel a favor. Without breaking any laws, they could swear a kind of allegiance to Intel, promoting its products and standards.

Even if Intel openly tells its portfolio companies not to give it favored treatment, in reality a small company may simply decide it's best to play ball with Intel. That may mean becoming a supplier to the company at the expense of selling to Intel's competitors. Or choosing to avoid areas that clash with Intel's agenda. Or quietly cutting back investment in a technology that threatens Intel.

Of course, no one will admit anything like this goes on. But as the government's antitrust case against Microsoft shows, hardball tactics are a way of life in high tech. Information technology has helped to create a New Economy based on prosperity and productivity gains, but old business practices die hard. The Octopus lives.

Which investment bank is #1 in lead-managed Internet IPO volume?

$1,042,000,000 TD WATERHOUSE Initial Public Offering Lead-manager June 1999	$416,592,000 free serve Initial Public Offering Joint Global Coordinator U.S. Bookrunner Joint International Bookrunner July 1999	$383,500,000 mp3.com Initial Public Offering Lead-manager July 1999	$144,900,000 USi Initial Public Offering Lead-manager April 1999	$107,217,000 Liberate Initial Public Offering Lead-manager July 1999
$103,500,000 Software.com Initial Public Offering Lead-manager June 1999	$80,500,000 autoweb.com Initial Public Offering Lead-manager March 1999	$79,695,000 COMMERCE ONE Initial Public Offering Lead-manager July 1999	$73,600,000 intraware Initial Public Offering Lead-manager February 1999	$73,600,000 phone.com Initial Public Offering Lead-manager June 1999
$72,000,000 APPNET Initial Public Offering Lead-manager June 1999	$69,000,000 CLARENT THE CLEARER. THE BETTER. Initial Public Offering Lead-manager July 1999	$67,275,000 careerbuilder www.careerbuilder.com Initial Public Offering Lead-manager May 1999	$64,664,000 TANNING TECHNOLOGY CORPORATION Initial Public Offering Lead-manager July 1999	$59,535,000 mortgage.com Initial Public Offering Lead-manager August 1999
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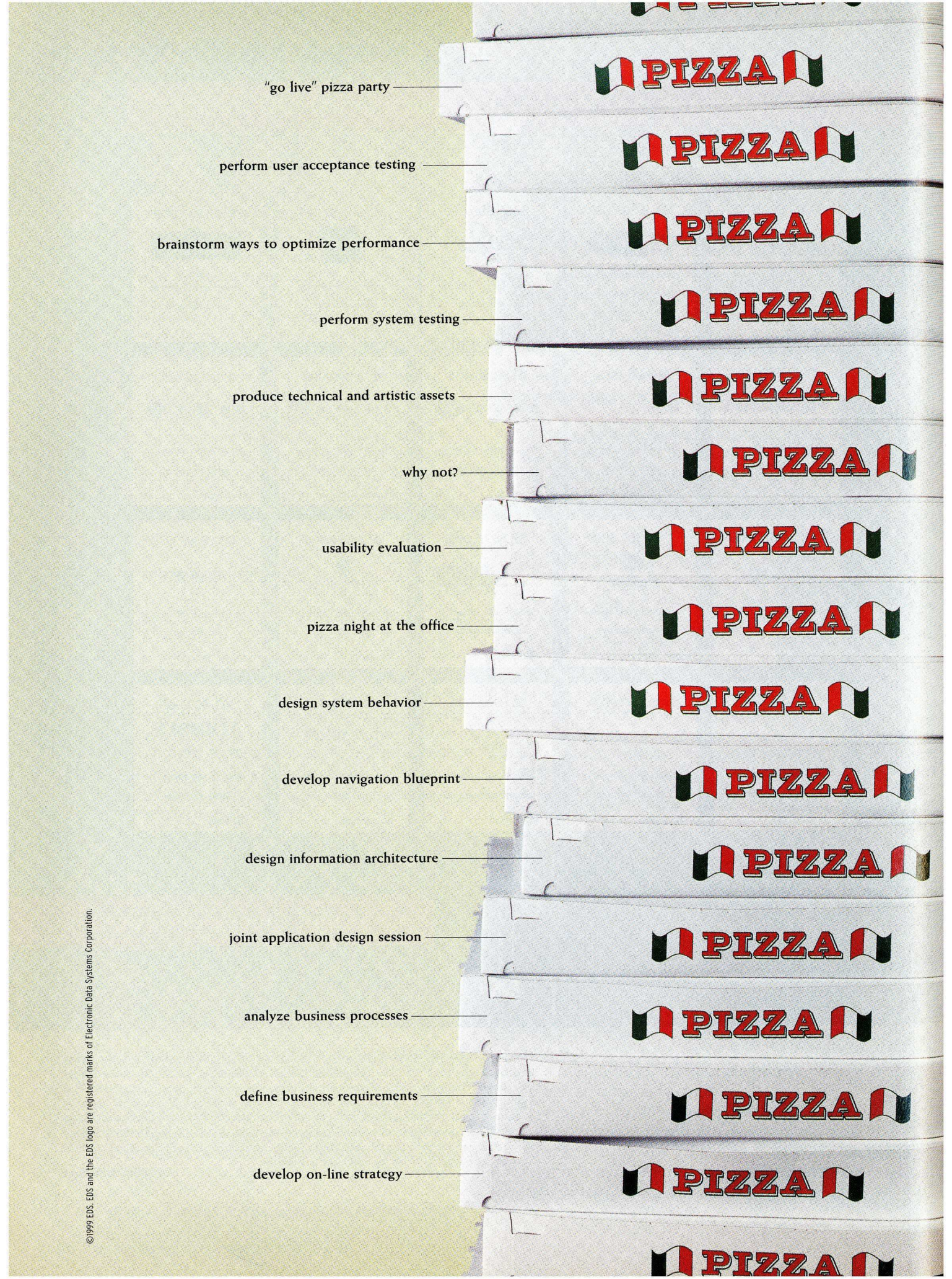

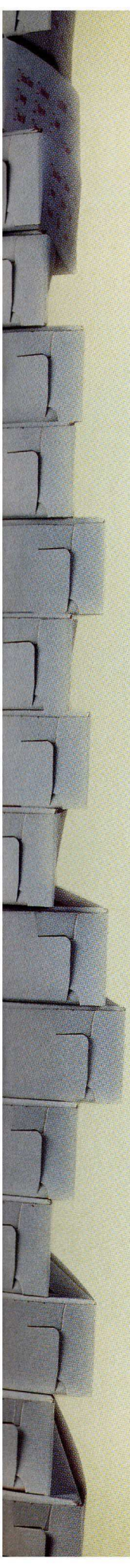

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You may know it when you see it, but before you can foster innovation in a company or nation you need to be able to get a grip on it. Meet the researchers who are trying to quantify this crucial but elusive process.

In Search of Innovation

BY ROBERT BUDERI

A BRIGHT LIGHT SHONE ON THE UNITED STATES AS BUSINESS EXECUTIVES, ACADEMICS AND policy leaders—including Al Gore—converged on MIT's glitzy Tang Center for the National Innovation Summit. It was the spring of 1998, and as the country savored one of its best economies ever, Harvard Business School professor Michael Porter sobered the powerful audience by pointing to dangers beyond the horizon.

True, U.S. companies had succeeded brilliantly in getting their houses in order, Porter said. But he and MIT professor Scott Stern were analyzing innovation in 25 nations—and preliminary projections from their "National Innovation Index" were not rosy. Indeed, based on such parameters as international patents filed, R&D spending and share of gross domestic product spent on higher education, it appeared the United States would tumble from the top spot to sixth place by 2005 *(see "National Numbers Game," p. 50)*. Porter delivered the news again in January at the World Economic Forum's annual meeting in Davos, Switzerland. As a summary of the controversial report warned: "All the good macroeconomic news may be distracting us from looming threats to long-term U.S. economic strength."

PHOTOGRAPHS BY STEPHEN SHEFFIELD

The Porter-Stern study addresses vital issues about the future of American competitiveness. But for those interested in predicting future trends in productivity, there's one lingering problem: The index doesn't measure innovation.

Because innovation is an abstract and difficult-to-measure concept, Porter and Stern's index chooses a simpler surrogate: patenting trends. "While it can be argued that patents are somehow related to innovation, nobody has ever established that," says Harvard Business School professor emeritus Richard S. Rosenbloom, a longtime student of the field. Therefore, while praising other elements of the work, Rosenbloom adds, "it is a misnomer to call it an 'innovation index.'"

It's a crucial distinction. In an era of unrelenting competition, innovation has become a priority for corporations, institutions and nations. Heightened interest is spurring widespread efforts to analyze what underlies the process and assess how firms and countries are doing, because good measurement is central to effective management.

Yet all efforts to date fall far short of the mark. "It's the holy grail of people working on the management of technology—being able to measure innovation," Rosenbloom sums up. "I don't think anybody has cracked it, not yet."

The good news is that those confronting the challenge believe, to borrow a phrase, the truth is out there. Their dedication to the search is engendering a series of promising advances. Patent analyses, despite their shortcomings, form a vital part of the picture. The National Innovation Index and other recent studies are inching closer to the ultimate goal by shedding light on the quality of inventions, not just their quantity. Meanwhile, other imaginative studies seek to identify the unseen "intellectual capital" that gives firms a leg up. These approaches are still in their infancy, but they're already helping to shape the policies of companies and nations alike.

Inside the Black Box

Innovation is a tough nut to crack because it involves much more than invention *(see "Invention Is a Flower, Innovation Is a Weed," by Bob Metcalfe, p. 54)*. Truly measuring the process of innovation means going beyond traditional analysis of big inputs such as R&D spending and outputs like patents to shine a light inside the black box of national and corporate competition. It's a problem that spans everything from investment in basic science to research and development tax credits, education systems, corporate programs, inter-industry dynamics and the entrepreneurial culture, all of which combine to fire the innovation process *(see "Four Pillars of Innovation" by Michael Dertouzos, p. 31)*.

Since many of these factors include qualitative as well as quantitative attributes, measuring innovation's inner stuff is enough to give any management guru fits. Indeed, executives have struggled with such issues since science steamrolled into business in the 19th century, primarily in the American and German chemical and electrical industries. What's new, though, are the intensity and magnitude of current efforts to track innovation.

The dawn of this modern era is sometimes traced to Harvard University economics professor Zvi Griliches' 1979 paper, "Assessing the contributions of research and development to economic growth." In it, Griliches proposed a theoretical framework for defining and measuring R&D, identifying and tracking its outputs—and charting their economic impact. Not content with theory, Griliches put his ideas into practice in the form of the Productivity Program at the National Bureau of Economic Research in Cambridge. It took years to build a foundation for deeper studies, notes program member and Harvard Business School professor Josh Lerner. But in the past decade, with the rise of powerful desktop computing systems that crunch hundreds of equations in seconds, he notes, "there's been a whole flowering of research around these issues."

The most significant initial finding was a strong link between research and development spending and overall productivity and growth. The connection prevails across every level of analysis: national, industrial and corporate. More recently, as the picture has been refined, much attention has centered on the most verifiable output of R&D, i.e. patents. In particular, researchers have devised ever more sophisticated ways to rank patents and evaluate them. On the level of individual organizations and firms, such measures are being used to pick potential marketplace winners and losers and even identify shifts in strategic focus.

Who Walks the Walk?

For instance, some cutting-edge researchers believe this approach can be used to pinpoint companies that will outperform their competitors. Francis Narin, president of CHI Research of Haddon Heights, N.J., has emerged as a pioneer in assessing firms' technological strength. Narin believes that, in looking at the patents a high-tech firm generates, three variables are crucial: "citation intensity," "science link" and "technology cycle time."

Citation intensity gives an indication of how influential a particular patent is based on how often it's cited in *other* patents. Science link represents the number of scientific papers cited in each patent, and technology cycle time is the median age of the patents cited in all of a company's recent patents; these last two measures form a way of quantifying the widely held assumption that the most innovative patents are closest to the forefront of science and technology.

Narin has long combined these three factors to rank firms in key high-tech industries. Now, however, he's going beyond just measuring to try to prove that high marks on these scales pay off finan-

Patents can yield clues about innovation at the corporate or national level. But numbers are only part of the story, so researchers are gauging quality as well as quantity.

cially. In a study published this spring in *Financial Analysts Journal*, he teamed with New York University finance expert Baruch Lev and doctoral student Zhen Deng to find out whether technological strength itself is an indicator of a firm's future financial performance.

The trio's hypothesis was that a company whose portfolio contains highly cited, science-rich patents is likely generating innovative technology, providing a marketplace advantage that will show up in future stock prices and market-to-book ratios—the stock price in relation to the value of a firm's hardcore financial assets. All told, they studied 388 companies in four high-tech sectors: chemical, drugs, electronics and "others."

Narin, Lev and Deng compared company results against industry averages, then gauged each firm's market performance over the next year or longer. In line with their hypothesis, the market-to-book ratios of companies with high citation intensity and high science linkage outdid those of companies ranked low in both categories by 25 percent. These "high-high" companies also tended to do better in the stock market, though results were more mixed.

Since just about every company these days claims to be "innovative," more sophisticated methods are needed to find out who walks the walk and who just talks the talk. Narin thinks his research can help. Armed with refined stock-picking parameters, in July he launched Investor TechLine, a $15,000-a-year database that provides monthly rankings of 250 firms to institutional investors.

By comparing actual market-to-book values to his technology-based ratios, Narin classifies companies as overvalued or undervalued. To get an idea of the power of the approach, consider this: A portfolio of equal dollar investments in Narin's 20 most undervalued stocks from last December 31 would have increased 50 percent over the next six months—a time when the S&P 500 rose only a few points. Beating the market by such a large factor "blows your mind away," Narin says.

"We Show the Money"

Part of the value of this analysis is that it can go beyond picking winners and losers to offering insight on a company's technology strategy. Take Dow Chemical. The Midland, Mich., giant slipped from 455 patents in 1989 to 263 in 1995 (although it still patented at twice the industry rate). Meanwhile, Dow was laying out substantially more to come up with each patent than its competitors, while its citation intensity ranked *below* the industry norm.

But that was only part of the story, because another Narin-Lev measure shows that Dow was getting much closer to the cutting edge: Science linkage had grown significantly, from below the industry average to almost double it. Technology cycle time, meanwhile, ran at the industry average. These two measures taken together indicated that Dow was patenting developments close to the cutting edge of science, as fast as competitors turned out more standard inventions.

The study tracked firms as a group and not individually, and therefore the researchers didn't check with Dow officials to find out whether these findings did indeed reflect changed internal thinking. But *TR* contacted Dow R&D vice president Richard M. Gross, who confirms that around 1990 his company did alter its strategy.

The strong science linkage, for instance, stems from a concerted push into new growth arenas that hinged on developing a more fundamental understanding of the science behind both its core existing businesses and promising emerging areas. For example, research into metallocenes—a new class of catalysts used to make plastics with more precisely tailored properties—allowed the company to develop improved polymers vital to everything from cushioning for high-end athletic shoes and sports equipment to thinner but stronger garbage bags.

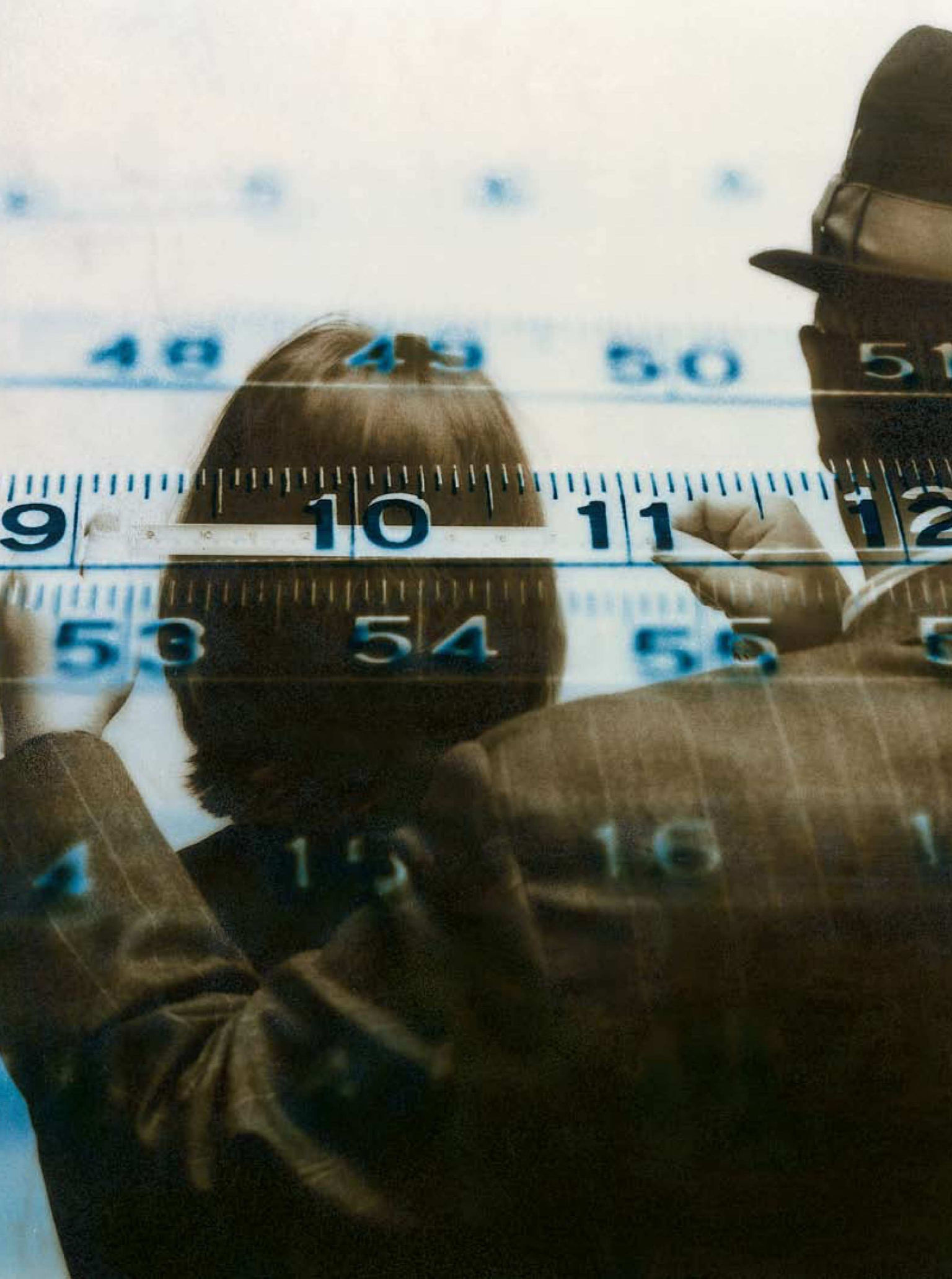
This science focus was linked to a broader push to raise patent quality. "We had encouraged quantity historically, as a lot of companies had," Gross acknowledges. Indeed, the since-dismantled patent honor roll at the main R&D building in Midland, Mich., spanned an entire wall, with brass plates bearing the names of top inventors. But as competitive pressures forced Dow's Inventions Management group—now called Intellectual Asset Management (IAM)—to examine the costs and returns associated with this vast portfolio, it got a shock. "We had a $40 million liability on just patent costs," relates Sharon Oriel, an IAM manager. "And yet we couldn't show that other part—what's the value."

That wake-up call triggered a vigorous campaign to drop, spin off or license patents that didn't fit the needs of Dow's 14 global business groups, and target future patenting more closely on the company's objectives. Working with Cambridge, Mass.-based consulting firm Arthur D. Little, IAM has developed proprietary methods of tracking patent status, costs and benefits, which it uses to facilitate business group planning. Oriel says this provides a new dimension to measuring innovation that resonates with what the "show-me-the-money" business groups have always wanted from research. Now her group wears T-shirts that say: "We show the money."

In only six months, a portfolio of 20 "undervalued" stocks picked by Francis Narin's innovation-based method would have increased a remarkable 50 percent.

Intellectual Capital

Moving beyond a broad-brush approach to dissecting the relationship between patents and innovation marks a big step forward. But patents certainly don't tell the whole story. In today's knowledge economy, many innovations are simply not patentable. Some of the most creative manufacturing and dis-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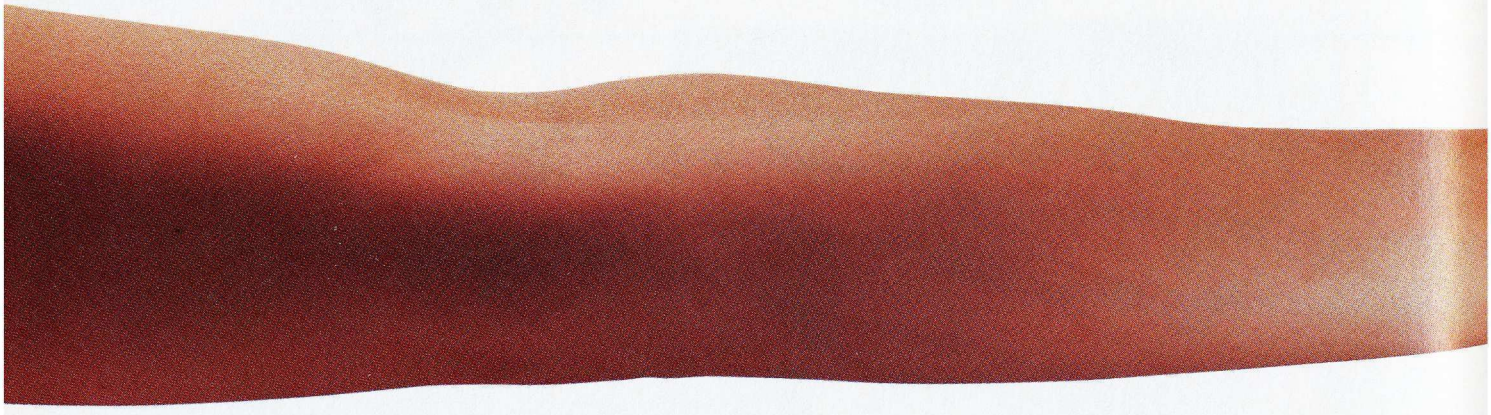

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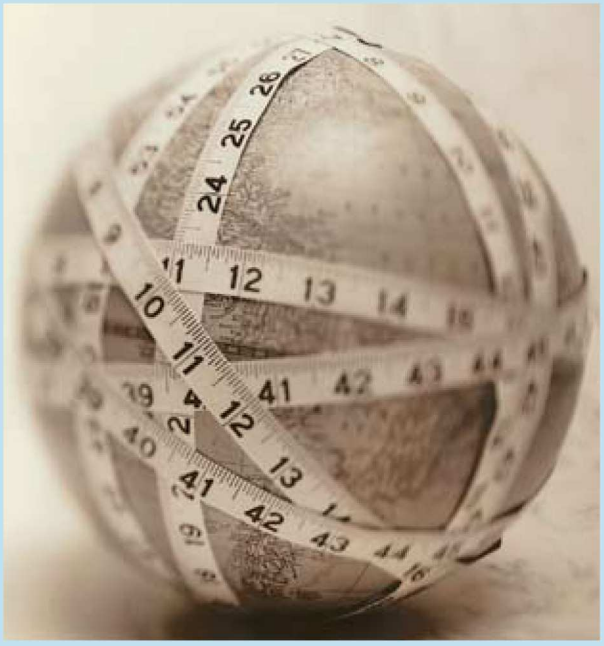
National Numbers Game

The United States is doing better than one innovation index would predict. Why?

It's hard enough to measure innovation at individual companies. But try doing it for nations, where progress waxes and wanes for reasons that run from wars to economic downturns, rendering it exceedingly difficult to make comparisons across boundaries and over time.

The National Innovation Index developed by Harvard's business guru Michael Porter and MIT number-cruncher Scott Stern marks one—controversial—attempt. Sponsored by the Council on Competitiveness, a Washington, D.C.-based alliance of industry, academia and labor, the project aims to measure not just a country's output, but its future innovative capacity—with an eye toward begetting a more informed public policy debate. In particular, Porter and Stern wanted to examine whether the United States was laying the foundation necessary to sustain its productivity edge a decade or more down the road.



Their study encompassed the United States and 24 other nations, ultimately ranking countries according to real and projected number of international patents per million residents. International patents are considered a better measure of productive output than total patents, because firms presumably would not incur the tremendous costs of transnational filings unless the inventions were unusually promising. Porter and Stern factored in eight variables, from R&D spending and personnel to higher education outlays and the strength of intellectual property protection; the researchers say these measures can be statistically weighted to explain 99 percent of the change in a nation's patent rate over time. Assuming a country's commitment to these areas would stay on its same trajectory, they projected future performance.

The results? Not good for the home team. Down tumbles the United States, from the top spot in 1995 to a mediocre sixth place in 2005. Japan will rise from third place to first, prophesies the index. Finland, Denmark and Sweden, joined by tiny Switzerland, all surpass the United States. In explaining the trend, Porter and Stern note, among other factors, that many foreign companies are spending a higher percentage of sales on R&D than U.S. firms, and that America's scientific and technical workforce is declining relative to other nations'.

Not everybody's buying this downbeat message. One notable critic of the index is Nobel laureate Arno Penzias. The former Lucent-Bell Laboratories research director argues that in today's knowledge economy, many innovations involve the integration of existing technologies in ways that may not be patentable—and so might not turn up in any patent-based analysis. "We are still using metrics based upon reductionist thinking," he stresses. "[It's] easier to measure stand-alone inventions than integrative innovations."

What's more, the actual number of patents granted to U.S. residents and corporations is running significantly ahead of what Porter and Stern predict. In fact, patenting by this group in the United States relative to the nation's size and spending had been flat or declining throughout much of the 1970s and early 1980s. In 1984, however, it reversed course and has risen at an accelerating pace for the last dozen years.

There are several possible causes for this mysterious patent bubble, including a recent strengthening of the patent-protection system that presumably encourages more filings, as well as a rush of software and biotechnology patenting. However, in a paper published last year, Harvard's Josh Lerner and Boston University economist Samuel Kortum examined these hypotheses and others—and shot them down. They noted that if U.S. legal changes were driving the surge, there should also be an uptick in patenting here by foreign inventors. Not only was the big rise confined to the U.S. side, American inventors were also patenting more abroad, where laws had not been changed. Similarly, Lerner and Kortum found a spike in filings that extended beyond software and biotech to roughly 70 percent of all patent classes.

Their preliminary conclusion is that the United States is winning the innovation race—at least as measured by patents. "What we are arguing is that, even if the shift in patent policy had a significant impact on firms' willingness to patent...there seems to be some fundamental shift that has happened in the level of innovative activities in the U.S. economy," says Lerner. He and Kortum theorize that changes in research technology, such as the widespread proliferation of computers and other information technology, more efficient research management or a concentration on the applied activities likely to generate patents could be fueling the trend.

Porter and Stern never claimed to have written the final word on measuring innovation. But while their index is far from perfect, they believe their results are close enough to start shaping policy. Indeed, the Council on Competitiveness is using the index's conclusions to push for a doubling of nonmilitary federal R&D spending over the next decade. Council president John N. Yochelson believes the issue to be a critical one. "The bread-and-butter challenge for the country's economic future is strengthening our capacity to innovate," he says. "It is very important that at a time when the U.S. economy is doing well that we ask ourselves what matters...and particularly how well are we doing in the area of developing the premium products and services that will support a high-wage economy over the long term."

tribution companies—think Dell—won't appear on any yardstick that tracks intellectual property. As a result, a lot of attention is shifting to other scales. Perhaps most notable is what's often called "intellectual capital"—the sum total of the seemingly "intangible" knowledge, processes, culture, customer and supplier networks and other factors that can ignite industrial creativity.

Intellectual capital might be the hot zone of gauging innovation today. NYU's Lev notes that in the manufacturing economy of the 1970s, the market-to-book ratio of S&P 500 corporations ran about 1:1. These days, it's around 6:1, while high-flyers like Microsoft come in around 25:1—largely on the basis of their intellectual capital.

"It's really mind-boggling when you think about this whole accounting machinery that ends up with a balance sheet that explains less than one-sixth of a company's real value," says Lev. "So we are talking here about an enormous asset which really is the engine of the success of companies and growth."

Earlier this year, Lev compiled a Knowledge Capital Scoreboard for *CFO* magazine ranking 47 large chemical and pharmaceutical firms. He and portfolio manager Marc Bothwell of BEA Credit Suisse Asset Management analyzed each firm's earnings for the past three years, as well as its projected earnings for the next three years. From the weighted average, or "normalized" earnings, they subtracted expected returns on tangible assets such as bond portfolios and physical equipment; the remainder, they assumed, represented knowledge-capital earnings.

For companies that are knowledge-rich, this kind of capital is a huge part of their success. Take Merck, considered one of the scientific leaders in drug development. In this analysis, Merck's normalized earnings were $5.5 billion. Its physical assets were expected to generate $343 million annually, while some $624 million in financial assets were projected to earn $28 million. That left a whopping $5.1 billion a year attributed to knowledge earnings. According to Lev's formula, this represents the return on intellectual capital assets totaling nearly $50 billion—which moved Merck to the top of the pharmaceutical pack, ahead of others with greater sales.

Intangible Assets

Studies like these are themselves on the cutting edge of their own field of research. For that reason, they entail a large number of assumptions that remain to be tested in subsequent work. Still, Lev's studies are helping fuel a growing movement to get companies to produce such data in quarterly and annual reports, much as they generate traditional financial information. Indeed, following a three-day intellectual capital symposium in Amsterdam last June, the Organization for Economic Cooperation and Development reported widespread international support for the voluntary reporting of knowledge assets.

On this front, the clear pioneer is Skandia Life Insurance, a Stockholm-based global financial services powerhouse, which has published an intellectual capital supplement to its annual report since 1994. The supplement has tracked turnover rates, the number of contracts generated per employee and the percentage of women managers. It also includes stories meant to illustrate trends behind the figures.

A story in the 1998 supplement called "Female Potential," for example, centered on a Skandia program aimed at bringing more women into sales leadership. The goal, according to the piece, was "to obtain more female leaders, and to actively eliminate obstacles to the realization of the full development potential of these women and add to the collective value-creating process within Skandia." Toward that end, each woman was paired with a "personal mentor" from a different business area. "The mentor's role is to be a dialogue partner and to be on hand for support and advice, while facilitating the candidate's continued development and career in the company."

If it all seems a bit touchy-feely, it's because innovation itself is still a somewhat mysterious combination of work, skill, inspiration and environment. But for companies concerned with staying on the leading edge, such factors have become paramount. Now corporations are taking fresh looks at the whole value-creation chain, seeking to maximize returns on everything from employee-training programs to the colleges of expertise that enable people to share knowledge and skills.

Mark B. Myers, senior vice president of Corporate Research and Technology for Xerox, concedes that astute managers have always paid attention to these issues. What's different now, he argues, is that the efforts are more sophisticated and they're starting to tease apart the deeper elements of innovation.

More and more, managers are trying to get a grip on the touchy-feely aspects of innovation. Tame these intangibles, they reason, and you can gain an edge on the competition.

Over the past two years, Myers has worked with Harvard Business School's Rosenbloom to develop methods for determining whether Xerox is investing correctly in key elements of innovation. This undertaking, which involves tracking decades of R&D expenses against revenue growth and benchmarking Xerox's investments against those of principal competitors, is still confined to tangible measures. But Myers is hoping the effort will lead him to greater inroads on the intangibles as well. After all, he notes, "a higher portion of the value creation in a knowledge-based economy versus a manufacturing economy may be contained on the intangible side."

To the extent that Xerox is onto something, it will still represent a rare victory for the measurement forces. Nevertheless, a host of corporate leaders, academics and others remain bent on prying the lid off innovation's black box. Each success promises to help the gears inside turn more smoothly.

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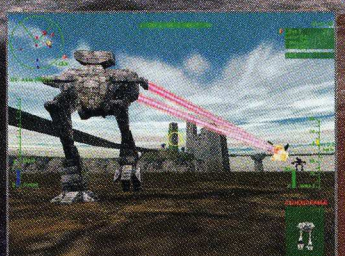

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Invention Is a Flower, Innovation Is a Weed

The inventor of Ethernet and founder of 3Com shares some lessons with young innovators BY BOB METCALFE

Bob Metcalfe's career traces the trajectory of innovation. He started in the academy, as an undergraduate at MIT and a graduate student at Harvard. In his doctoral dissertation he laid the theoretical foundations for a novel method of boosting the power of personal computers: network them. At Xerox PARC, he turned that theory into something called Ethernet. Xerox wasn't particularly successful at exploiting Ethernet commercially, so Metcalfe decided to try himself, founding 3Com to do the job. After many incarnations at 3Com, he cashed in his chips and became, in his words, a "technology pundit," who writes a column for InfoWorld, *organizes some of the information world's best conferences, and sits on the board of* Technology Review. TR *asked Metcalfe to tell us what he learned as he followed the trajectory of innovation from the lab bench to the boardroom and beyond.*

Prologue

Why should you listen to me about innovation? Maybe you shouldn't. (Especially if what you need is gentle encouragement.)

True, I lived for eight years in Boston's Route 128 high-tech innovation zone, back when it was working. True, I lived and prospered for 22 years in Silicon Valley. True, I invented Ethernet, a computer networking technology that now connects more than 100 million computers to the Internet. True, 20 years ago I founded 3Com Corporation, which now does more than $5 billion in annual sales. And true, my personal fortune is a significant fraction of a milliGates.

But Silicon Valley-style high-tech entrepreneurship is certainly not the only way to innovate. It's just that, right off, I can't think of any others.

Disclaimers

Before sharing a few lessons I've learned from inventing and innovating, I'd best disclaim a bit. Consider the fact that today we have computers fast enough to com-

ILLUSTRATION BY HANOCH PIVEN

pute the trajectory of a thrown rock in real time. If you wanted to gather the equations to compute the rock's trajectory, the last thing you would do is interview the rock.

Most successful entrepreneurs I've met have no idea about the reasons for their success. They were thrown—like rocks. I had the good fortune to be thrown into Silicon Valley. My trajectory was a mystery to me then, and only a little less so now.

Another disclaimer: I'm a sample of one. My experience is not statistically significant. So you're going to have to read a lot of lessons learned by many different innovators before you can put together something that holds up. And even after you do that, keep in mind that after 40 years of tennis, I can tell you to get your racket back early, move your feet, and step into the ball. But then you're going to have to spend a lot of time on the court practicing before you can put it all together and beat me.

Enough disclaimers. Here are some lessons I *think* I've learned.

1. Selling Matters

I have a six-story townhouse in Boston overlooking MIT on the Charles River. I often invite young engineers and would-be entrepreneurs over to schmooze. Many of them tell me my townhouse is beautiful and they hope to invent something like Ethernet that will get them such a house.

The picture they have in their heads is of me lounging around on the beanbag chairs in a conference room at Xerox PARC in 1973. They see me having this idea for a computer network and submitting it as an invention proposal to Xerox. Then they envision me putting my feet up and letting the royalties roll in until I have enough to come up with the down payment on the townhouse with the river view.

My picture—the actual picture—is different. It's the picture of *innovation rather than invention*, the weed instead of the flower. In my picture it's the dead of winter and I am in the dark in a Ramada Inn in Schenectady, New York. A telephone is ringing with my wake-up call at 6 a.m., which is 3 a.m. in California, where I flew in from last night. I don't know yet where I am, or where that damn ringing is coming from, but within the hour I'll be in front of hostile strangers selling them on me, my company, and its strange products, which they have no idea they need.

If I persist, selling like this for 10 years, and I do it better and better each time, and I build a team to do everything else better and better each time, *then* I get the townhouse. Not because of any flowery flash of genius in some academic hothouse.

Most engineers don't understand that selling matters. They think that on the food chain of life, salespeople are below green slime. They don't understand that nothing happens until *something gets sold.* The way I think about it is that there are three sets of people in the world. There is the set of people who will buy your products no matter what (think of your mother). There's the set who will never buy your products (think of your competitors). Both are much smaller than the set of people who will buy your products if the products are competently sold to them. That vast middle set is why sales is so important, and it represents one of the key differences between invention, which comes up with a brilliant new idea, and innovation, which gets that inspiration out into the world.

Sales may not matter in invention, but it matters—in a very big way—in innovation.

2. At a Startup, Jobs Grow Faster Than People

In 1982 I suddenly lost my job as 3Com's CEO and became our vice president of sales and marketing. Take this as a measure of our desperation. I knew we needed feet on the street, people to actually ask our customers for orders. I didn't have too many choices—it wasn't a very big company at the time—so I started looking over the available candidates.

Dave didn't initially look very promising, since he wasn't in sales. (He was a production engineer.) But he was single, his dad was a salesman, and he could move that week, so I assigned him the entire eastern United States as his 3Com sales territory. This is one of history's bad decisions with a good outcome.

Since his background wasn't in sales, Dave wasn't a good bet to succeed in the huge job I gave him. But he was smart and energetic and he learned fast. Pretty soon, orders started doubling. The volume of sales was improving so quickly that I "promoted" Dave—from head of the entire eastern United States to head of the northeastern region. Again, he succeeded, and I was able to "promote" him again, this time by giving him the Washington D.C. metro area. After another strong run of successes, Dave went up the down staircase again by taking over all private label sales in Washington.

If you counted from the top, as people tend to do in big companies, Dave was getting *demoted* each time. If you counted from the bottom, each reduction in territory in our rapidly growing company was a big promotion with more responsibility and higher compensation. This is an example of how in small successful startups the jobs grow faster than the people, not the other way around, the way they do in big companies.

3. Don't Hire—Recruit

Lesson #2, that jobs grow faster than people in successful startups, implies something very important about the people you bring into such a startup.

First, don't "hire" anyone. B people hire C people—they collect resumes and choose the person they want to honor with a job. A people *recruit* A people. The people you need for a growing startup already hold jobs much bigger than the ones you need to fill. You have to recruit them, beg them almost, to take the small jobs you're offering. Those with imagination will see that the company has the potential to grow so quickly that the small job will soon be much bigger than the stable position they hold at a big company. Forget about big company notions of performance. A people can perform easily 10 times better than B people, sometimes 100 times, or 1,000. The worst thing you can do is rush to fill a job with a B or C person. That could be very costly, perhaps even fatal, to your company. Wait until you can recruit the A person who can see the future and grow with it.

4. People Have Operating Ranges

The fact that jobs are growing so explosively at startups has other important consequences. Consider operating ranges. Everybody has one.

From $0 to $1 million per month I ran sales and brought in the orders, mostly through personal selling. After that, sales became too technical for that approach to work. Mike took over and carried the company from $1 million to $3 million per month. After a brief stall, Chuck took us to $5 million per month. John took over from Chuck to get us to $25 million per month. Then Bob took the company to $400 million per month. In each of these cases, our head of sales succeeded within his operating range. After that, a ruthless change had to be made to bring the company to its next plateau.

How do you know when it's time for a change? How can you tell when the person who did such a great job six months ago has hit the upper limit of his or her operating range? The first sign is a decline in performance—salespeople missing quotas, engineers slipping schedules. At first it looks like the plans were too ambitious; then it's everybody else's fault. At some point, unless things start improving, sometimes even before the proof is conclusive, changes must be made. You have to be able to say, "If you can't do it, we'll just have to find someone who can." If you wait too long for the person to learn what they need to know or for conclusive proof of whose fault it is, you may bring the whole enterprise down. Better to risk the lawsuit for wrongful discharge and save the venture.

5. Don't Listen to Your Customers

In 1982, 3Com Corporation was the sole supplier of Ethernet cards to a startup called Sun Microsystems. These cards were for Multibus-compatible computers, and so internally we called them MEs (really). Sun and its competitors were buying MEs at ever-increasing rates, and they wanted us to make a cheaper, faster next-generation card. Our salespeople were right there with our big customers: They demanded we work on what internally we called the ME II (naturally referred to internally as the "me too").

We knew, however, that Sun was planning to design Ethernet connections into their computers, and that Intel, designer of the Multibus, was planning a competitive ME. Despite overwhelming customer demand, we decided not to develop the ME II. Some of our salespeople quit in disgust, because we were "not listening to our customers."

They were right; we weren't. Instead, we invested the time of our excellent engineers in designing an Ethernet card, called internally the IE, externally the EtherLink, for the new IBM Personal Computer. Today, there are no Multibus computers left, but 3Com ships more than 20 million EtherLinks per year.

The lesson? Well, of course I'm taking some license by saying that the lesson is you shouldn't listen to your customers. The real lesson is that you have to choose which customers to listen to very carefully. And, even then, you cannot necessarily give them what they say they want. You have to develop products that your customers will need by the time you are able to deliver them. If you don't, when the development cycle is finished, and you're ready to ship, you will be offering what the customer said he wanted last year. And any salesman will tell you it's easier to give a customer what he needs now than to sell him something you insist he said he wanted last year.

6. Plan for Success

But if you do look ahead successfully and see what the market wants, you will only create new problems. During 1983, for example, 3Com was in the tornado for exactly this reason: We had ignored our customers and salespeople and guessed right about what the market would want—Ethernet for personal computers. In the third quarter, we grew 85 percent in three months, which almost killed the company. We sold much more than we could deliver, leaving a backlog of unsatisfied customers for our competitors to unhook. We didn't have enough people to answer all our customer support calls. Our production programs slipped behind schedule.

I remember our CEO, Bill, saying we would never grow that fast again. But I pointed out to Bill that Compaq had the year before gone from zero to 10 times our size in one year. Our problem was not that we had grown 85 percent in three months. It was that we had planned to grow only 15 percent. Which is to say that you can plan too conservatively. (I hasten to add that if you have to err on one side or the other, it is better to plan conservatively. Just don't overdo it.)

7. Be an Entrepreneur, Not a Visionary

In 1982 my board of directors starting calling me a visionary, and I ate it up. Next thing I knew, I wasn't CEO anymore. Turns out, nobody wants visionaries running companies. At my level of the game, being called a visionary was faint praise.

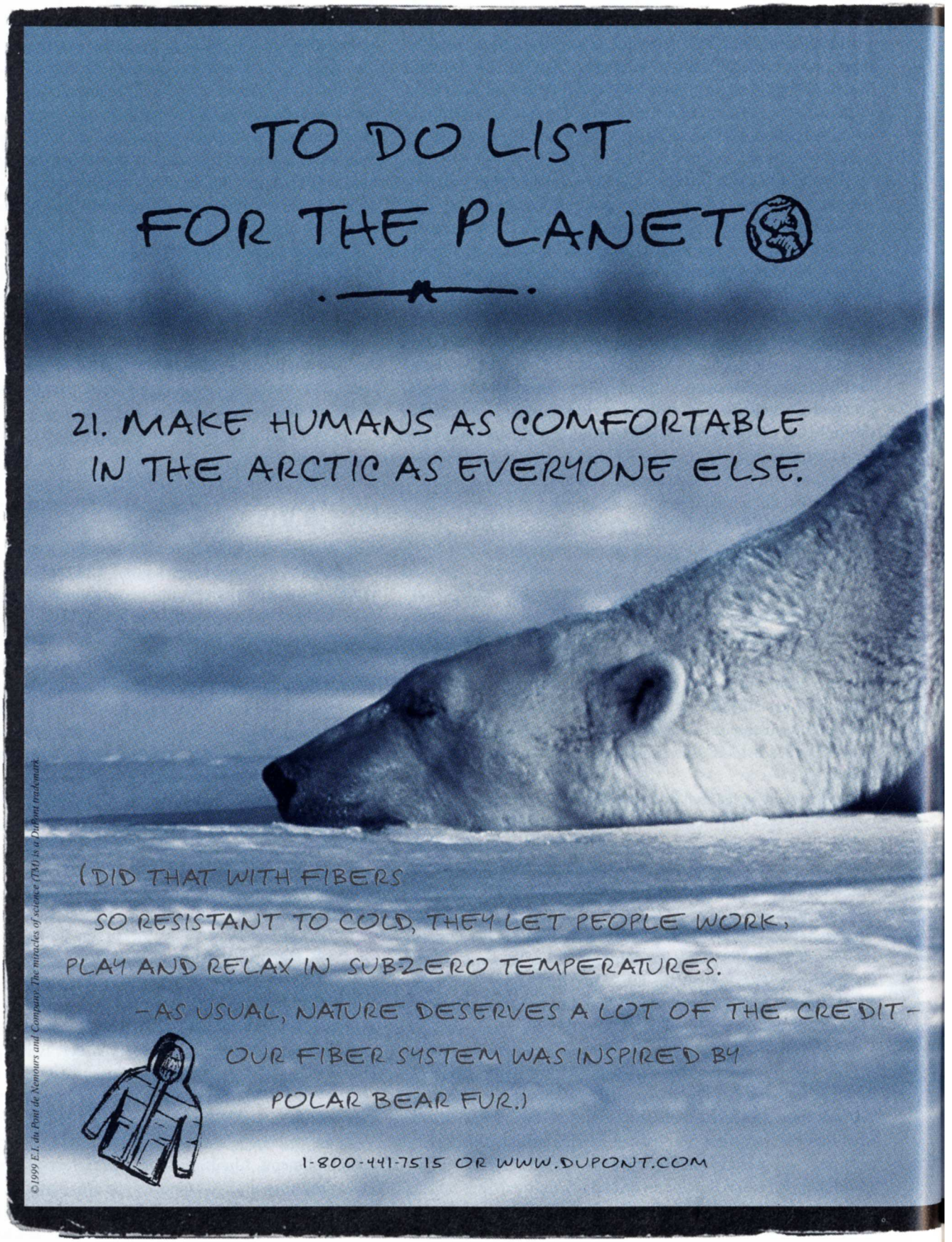
Here's the difference between a visionary and an entrepreneur. Both have visions, which are a dime a dozen. But an entrepreneur has, in addition to visions, plans. In addition to plans, actions. You might have heard that 80 percent of winning is just showing up. Well, showing up is an action, like taking that wake-up call in the dark in the Ramada Inn in Schenectady. I wouldn't touch a visionary with a 10-foot pole.

Being a company's proud founder is also foolish. As they build their companies, many people walk around saying to their employees, "I am the founder and you're not." You want every employee of your company to be a founder. To have and therefore *feel* ownership.

8. Know Your Own Operating Range

In 1990, I "retired" from 3Com exactly 11 years after incorporating it. I should have gone three years earlier. Twice the board of directors chose someone other than me to be CEO of 3Com. In 1982, when I didn't flounce out the door, but instead got sales and marketing. And again in 1990, when I retired amicably.

Putting together the board of 3Com was one of my proudest accomplishments. I built that board with the best people I could find. When they decided someone else was better qualified to be 3Com's CEO, who was I to argue? Both times, in retrospect, they were right. By 1990, 3Com had outgrown me. Fortunately I had a board smart enough to know that I had succeeded in moving 3Com out of my own operating range. You should be so lucky.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Interfaces: The Century's Top 10

Peaceful coexistence between human beings and machines requires clear communication. The best systems convey information so elegantly that we hardly think about the power they give us—boundaries dissolve and we become one with our technologies. The editors of *TR* picked 10 of the most ingenious and important. BY DEBORAH KREUZE

Loudspeaker

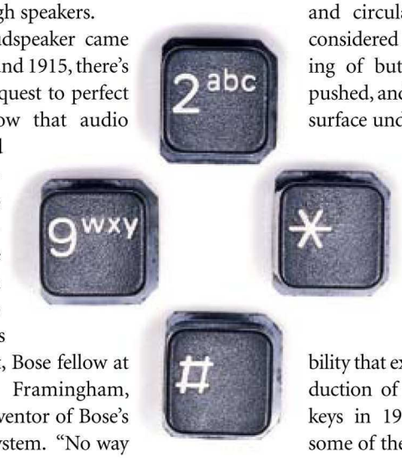
Early-twentieth-century poet G. K. Chesterton once said: "The moment in history when we had nothing important left to say was marked by the invention of the loudspeaker." The device makes it possible to listen to a Wagner opera—or any other "unimportant" stuff—while taking a bath, riding the subway or hiking in the forest. We can hear the electronically preserved voices of people long dead, as well as a universe of sounds unlike anything in nature. In a movie theater, loudspeakers surround us with sound and transport us into illusion. From Hitler to Hendrix, the century's charismatic figures have reached the public through speakers.

Since the loudspeaker came on the scene around 1915, there's been a constant quest to perfect the illusion. Now that audio recording and storage technologies are so good, loudspeakers are "easily the weakest link in the home audio system," says William R. Short, Bose fellow at Bose Corp. in Framingham, Mass., and co-inventor of Bose's Acoustic Wave system. "No way am I going to sit in my living room and imagine that I'm actually in Symphony Hall. It just doesn't happen, and we really don't know why yet."

Contribution to the lexicon: "Pay no attention to the man behind the curtain!"

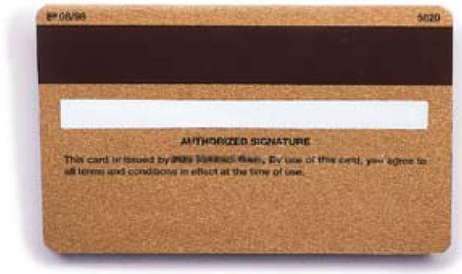
Touch-Tone Telephone

AT&T introduced "Touch-Tone" push-button phone dialing service in November 1963. By all accounts, practically everyone who tried it liked it better than rotary dialing. Bell Labs researchers went to great lengths to make sure people would accept the new interface: They tested 16 different arrangements of buttons, including crosses and circular patterns. They also considered sizes, shapes and spacing of buttons, springiness when pushed, and even the contour of the surface under the fingertips.



Cutting phone dialing time in half is nice, but from the beginning the intention was to transform the telephone into a remote data entry device—a capability that expanded with the introduction of the "*" and "#" keys in 1968. Though some of the services originally envisioned, such as using a telephone to turn on home appliances, have yet to materialize, the Touch-Tone phone has made possible phone trees, voice mail and a host of other services. Of course, sometimes the best way to get service is still to pretend you have a rotary phone and just stay on the line.

Contribution to the lexicon: "Press 1 for..."

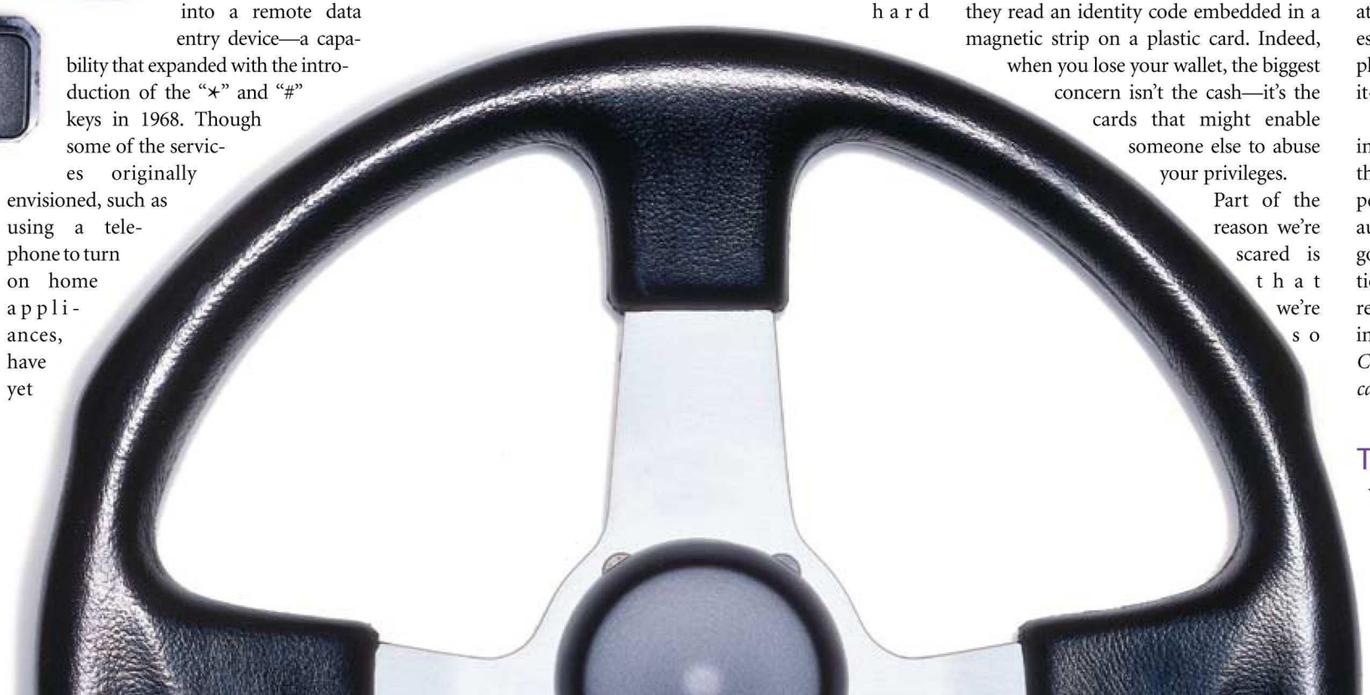


Steering Wheel

The first cars had tillers. Tillers worked, but they transmitted the vibration from primitive roads to the driver's hand, making it hard to steer. When engines moved to the front of the car, the increased weight made tillers impractical. The steering wheel puts a gear system between you and the car's wheels, offering a mechanical advantage and isolating you from vibrations. Despite this extra layer of insulation, a good steering wheel manages to give the driver a feeling of intimate contact with the road.

One unforeseen problem with the wheel was that, as cars got speedier, people started getting impaled on steering columns in crashes. In the 1950s, concept cars were developed that did not have steering wheels—but the public wasn't interested. A car without a steering wheel just isn't a car.

Contribution to the lexicon: "Take the wheel"



Magnetic-Stripe Card

Machines let us through doors, dole out money, and extend credit. To do these jobs, they read an identity code embedded in a magnetic strip on a plastic card. Indeed, when you lose your wallet, the biggest concern isn't the cash—it's the cards that might enable someone else to abuse your privileges.

Part of the reason we're scared is that we're so good at abusing our own privileges. In the early 1970s magnetic stripes on credit cards streamlined the authorization of credit card purchases, making them more attractive to retailers; combined with interest charges and new kinds of payment plans, the magnetic stripe helped the credit-card industry gorge America on credit.

Will new incarnations of plastic data in the form of "smart cards" go even further and make mag-stripe cards disappear? Not so fast, says David Warwick, author of *Ending Cash*. "Chip cards are going to find niches in certain applications," he says, "but I don't see them replacing credit cards. No one wants to invest in new terminals."

Contribution to the lexicon: "Swipe your card."

Traffic Light

When African-American businessman Garrett Morgan patented the traffic light in 1923, trains had been using automated lighted signals for some time. But trains run on set schedules, in

PHOTOGRAPHS BY VITO ALUIA

single file, and it's no small task to stop; therefore, the default message from a train signal is "proceed." Traffic lights for automobiles have a quite different task, and more often than we'd like, it's to tell us to stop.

We hate being told to stop. Road-rage expert Leon James, professor of psychology at the University of Hawaii, says we link self-esteem to the gas and brake pedals. "If you see a light turning yellow, you have to accelerate. If you have to stop because the light turned red, you feel crestfallen." James calls the intersection a "psychodynamic zone." If so, it's a zone increasingly under the dominion of the superego rather than the id. Some new traffic lights can take pictures of the license plates of cars that run red lights. The offender later receives a ticket in the mail—or a printed driving lesson. Others show drivers their current speed. At a traffic light, says James, "a lot can be done between the city transportation department and the driver. It's a communication hotspot."

Contribution to the lexicon: "Give it the green light"

Remote Control

The universal desire to avoid television commercials was the driving force behind the development of the remote control; the president of Zenith—of all people—hated the interruptions. The first remote, developed by Zenith in 1950, ran a cable from the viewer to the set. The first wireless remote, introduced by Zenith in 1955, used light sensors; later models used ultrasonics. Infrared remotes, which came along in the early 1980s, were so cheap everyone could afford them. Today the remote is standard equipment; 99 percent of television sets and 100 percent of VCRs come equipped for action at a distance. Especially for children who grew up with remote controls, surfing from channel to channel is part of the television viewing experience. Remote controls have been blamed for making us couch potatoes, but that's an unfair rap; it's not as if people without remote controls used to get up and change the channel frequently.

Contribution to the lexicon: "Channel surfing"

Cathode-Ray Tube

The cathode-ray tube (CRT) made its debut in 1897 in an oscilloscope, developed by German physicist Karl Ferdinand Braun. The "killer app" for the CRT, of course, was television, which appeared in the 1920s but didn't enter most American homes until the 1950s. Now it's everywhere. "TV is the main experience of waking life for most people in western industrial nations," claims Jerry Mander, author of *Four Arguments for the Elimination of Television.* That may be overstating the case, but not by much; the average American watches several hours of television a day.

Put a computer interface on the screen, however, and we're not quite so passive: We interact with it, turning the screen display into a means to an end rather than the end itself. But the emergence of terms like "Internet addiction" illustrates that often many of us would rather sit at a CRT than do anything else.

Contribution to the lexicon: "The tube"

Liquid Crystal Display

Television and computer screens convey massive amounts of visual information. The downside? They're found in a big heavy box, because they generally require a cathode-ray tube. Liquid crystal displays (LCDs) make graphical displays portable. Although liquid crystals were discovered in 1888 by Austrian botanist Frederich Reinitzer, they weren't used for displays until 1971, when Hoffmann-La Roche patented the "twisted nematic" LCD—the kind now found in calculators and watches. The active-matrix LCD, in which every pixel is controlled by a transistor, arrived in the 1980s, making possible laptop computers, miniature TVs and portable DVD players.

Although LCDs still have "issues of video speed and viewing-angle dependence" to be worked out, Webster E. Howard, vice president for technology at FED Corp. of Hopewell Junction, N.Y., predicts that thin, flat, liquid crystal displays will replace the bulky CRT monitors on our desks within five years. If they come into widespread use, he says, LCDs will owe their success to laptop computers: "The need for the portable computer was what made possible the investment in this technology that ultimately led it to be economical and cheap."

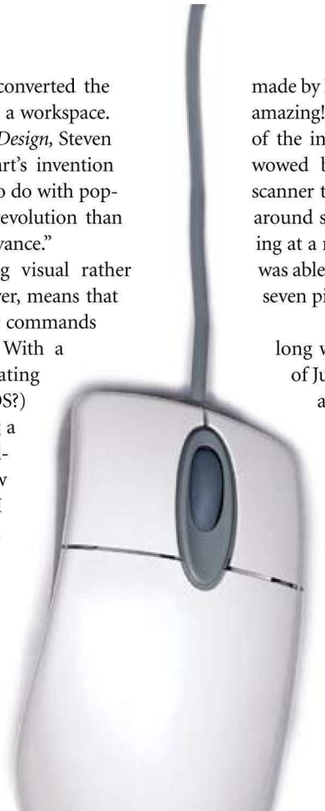
Contribution to the lexicon: "Laptop"

Mouse/Graphical User Interface

"When I started with the mouse, very few were taking seriously that people would want to work online at a computer display," says Douglas Engelbart, who invented the mouse and graphical user interface (GUI) in the 1960s. His mouse/GUI combination, further developed at Xerox Palo Alto Research Center (PARC) in the 1970s and popularized by Apple in the 1980s, made a computer's contents visible. Before that, to edit a computer file, you had to remember its name and location. The reduced demand on short-term memory, combined with a visual-spatial environment users enjoyed, converted the computer display into a workspace. In his book *Interface Design,* Steven Johnson says Engelbart's invention "probably had more to do with popularizing the digital revolution than any other software advance."

Making everything visual rather than linguistic, however, means that semantically complex commands get left in the dust. With a command-line operating system (remember DOS?) a task such as making a copy of every file ending in ".txt" took a few keystrokes. A GUI offers no shortcut. Engelbart, whose original interface put a mouse in one of the user's hands and a special "chording" keyset in the other, thinks today's GUI is awfully primitive: "Here's the language they're proposing: You point to something and grunt." Our cave-dwelling ancestors would have understood.

Contribution to the lexicon: "Point-and-click"

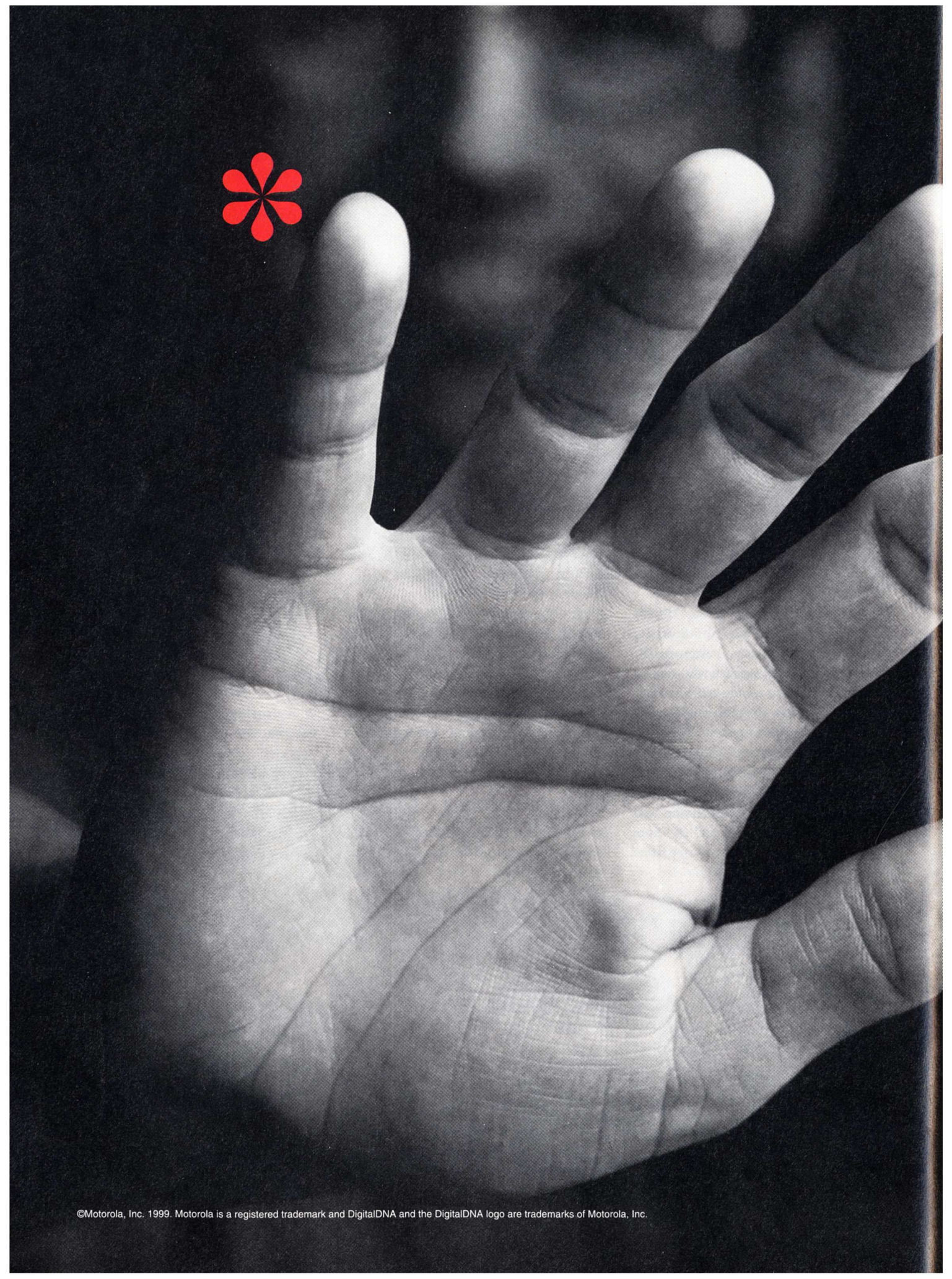


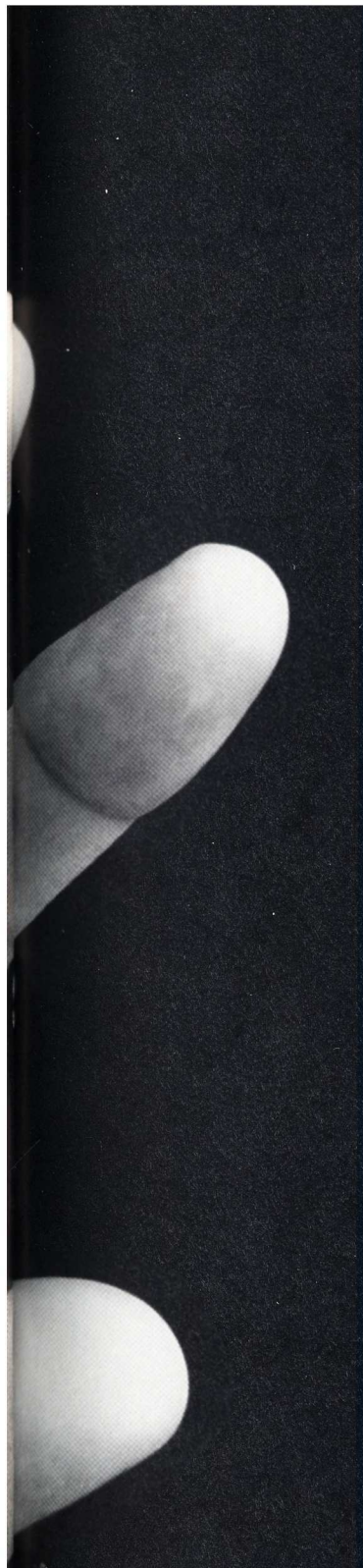
Barcode Scanner

In February 1992, George Bush was given a demo of a supermarket barcode scanner made by NCR. His response? "That's amazing!" Contrary to news accounts of the incident, however, he wasn't wowed by the mere existence of scanner technology, which has been around since 1974. He was marveling at a new, improved version that was able to read a barcode torn into seven pieces.

Scanners have come a long way since the first 10-pack of Juicy Fruit gum was scanned at Marsh Supermarket in Troy, Ohio. The initial draw for companies was accuracy of data entry: Barcode readers made a lot fewer errors than cashiers. But lurking in the laser's capability was the potential to collect vast amounts of information—on what products are selling, and when, and in what combinations. Says Craig Maddox, product line director for barcode scanners at NCR, "it was a good 15 years before the grocery industry started to use the data." Nowadays, retailers compile terabyte-sized databanks of every transaction in their stores and sell it back to vendors; barcodes have also speeded communication across the whole supply chain so much, remarks Maddox, that "some stores...don't pay for the product until it's already sold."

Contribution to the lexicon: "Scan it"





BiOtech On the MOve

One of the industry's founding fathers, Nobel laureate Phil Sharp, talks to TR *columnist Stephen Hall about the origins—and the future—of this high-tech business.*

Q & A

Phillip A. Sharp has enjoyed a front-row seat for the revolution known as biotechnology. As a young professor of biology at MIT in 1977, he checked out—at the request of several venture capitalists—an obscure California company called Genentech, which had the preposterous notion of using recombinant DNA to create pharmaceuticals. Later that year, when Genentech announced it had made a human protein from a synthetic gene, the world learned publicly what Sharp had understood privately: Genetic engineering technology would transform medicine.

In the spring of 1978, Sharp had the chance to put theory into practice. Those same venture capitalists recruited him and other prominent biologists from the United States and Europe to form the core of a new startup. The result, Cambridge, Mass.-based Biogen, remains one of the pioneering biotechnology firms; today, Sharp serves on the company's board of directors and chairs its scientific advisory board, assessing potential research initiatives and overseeing the journey of drugs from lab bench to market.

Sharp's own journey in science has taken him far from the Kentucky tobacco farm where he was born on D-Day in 1944. In 1974, after postgraduate stints at Caltech and Cold Spring Harbor, he came to MIT. In 1993, Sharp shared the Nobel Prize with Richard Roberts for research showing that genes are not arrayed as continuous stretches of DNA, but rather are spliced together during cellular processing.

Stephen Hall first interviewed Sharp 15 years ago while researching his book on the birth of biotechnology, *Invisible Frontiers*. In June, journalist and scientist sat down in Sharp's office at MIT's Center for Cancer Research. Kentucky still audible in his soft-spoken words, Sharp offered a down-to-earth, insightful perspective on the shape of the biotech industry, the difficulty of making potentially remarkable new therapies work—and the place of hope in the world.

PHOTOGRAPHS BY JOHN SOARES

TR: You were there at the beginning of biotechnology. How has it changed?

SHARP: Biotech began in 1976 with Genentech, and the evolution of the community followed a standard progression where new biological discoveries created opportunities to look for novel drugs and treat diseases. Venture capital funded your early efforts, and as you developed your technology you were able to strike relationships with large companies. You leveraged that either into a free-standing, vertically-integrated company or into a substantive research organization that ultimately was acquired by a larger pharmaceutical company—this was a standard paradigm for the last 20 years.

What we're seeing now is that biological innovation is continuing, as are the exciting opportunities. But the appetite for new biotech startups, on the part of both venture capitalists and financiers in large

companies, is more muted than it has ever been. There are 1,300 companies out there, and that's a lot of capacity in the field. The other factor here is, given the Internet venture capital explosion, I suspect we're hearing a large sucking sound as the VC money goes to something that turns over quite a bit quicker than a biotech organization.

TR: What will having fewer opportunities to launch new biotech ventures mean to the field in, say, the next 10 years?

SHARP: The startups that are already in place there will continue to do what they have done in the past. A few will get a product and succeed to vertical integration, but more and more of them will ultimately become part of other organizations. This consolidation in the biotech community, as well as the growing acquisition of biotechnologies by large pharmaceutical and chemical companies that want more biological exposure, is a major shift that started in the last year or two.

Still, I don't believe there will be a *decrease* in the amount of activity—the total number of employees will continue to go up because the opportunities are there. It'll just be organized in different ways, with fewer small organizations and more larger ones.

TR: Is there any area that's flourishing within these new models for biotech?

SHARP: There are a number of very prominent companies that have been built on providing access to genomics. Millennium here in Cambridge is one which has done terribly well at developing new working concepts around genomics and human genetics and bringing all that together in a technology house that a large number of companies have struck associations with. That's become a paradigm for the rapid development of an organization around a new technology and a new insight.

And there's a lot more to be done in genomics than has been done. The human genome won't be completed for another two years, probably. The functional genomics field is just emerging, where people are taking the catalogue of known genes that comes from the sequencing and then using them to explore biology—in drug development, for example, you could look at how genes are expressed in different parts of the body and use the information to determine how your drug is working and how a drug *should* work if it was curing the disease.

We need to push functional genomics even further: In many cases we're looking at millions of cells at a time. But get down to one cell and you have the ultimate resolution, you can take a single diseased cell and understand what's going on within it. That should be doable with the tools we already have.

TR: Perhaps that "sucking sound" you mentioned represents the fact that investors have finally understood why biotech is not like electronics: You don't have to do a clinical trial (which adds years to the development process) for a chip. Is the risk in biotech simply much higher than it is for, say, a hard drive?

SHARP: The risk is higher, but the payoff is higher. Still, if you look post-World War II, there have been very few large pharmaceutical companies established. Syntex, which developed the birth control pill, was one of the few to emerge in that period. The most prominent biotech company now is Amgen, which has a market value, I think, in the $30 billion range. Biogen is number two. Genentech is no longer freestanding by any definition, and Chiron is nearly owned by Novartis. You can look at how small that list is and say, "It's *really* hard to get there!"

TR: There's a sense that people are creating a startup these days based not on the hope that they'll ultimately make products and become a fully integrated company, but that they'll have a successful business plan and an I.P.O. and then essentially cash out.

SHARP: Well, that's been the basic business concept for the last 10 years. It may not be explicitly stated that way, but companies develop a technology and then license it to multiple large corporate partners, relinquishing a lot of control and a lot of the rights in the process. They all, by and large, have plans that say, "We will retain a part of this technology and develop our own products." But if you look at how these companies allocate their resources, the major manpower thrust goes toward those corporate relationships, and maintaining those relationships.

TR: If you look back now to the mid-1970s, what challenge did you most underestimate in starting a biotech company?

SHARP: Business acumen—knowing *exactly* where this technology fit into developing pharmaceuticals and how one needed to invest to make that happen.

What did we underestimate in terms of technology? Well, the first set of products we put on the list were interferons. And we underestimated how difficult it was going to be to find and prove the efficacy of these proteins. The interferons were wonder drugs, but were available in such minute amounts you couldn't test them! So a lot of the data was really untrustworthy. It took a long time in the clinic to find out how to use them, and they're still being developed. We originally thought interferon would be a drug for cancer, and it turned out to be a drug for multiple sclerosis. It's *amazing!* It's amazing how difficult it is to find drug opportunities.

TR: On the plane up, the person sitting next to me was reading *Golf Digest*, and there was an ad in it for SmithKline Beecham's new Lyme disease vaccine. I feel reasonably confident saying this is probably the first time a vaccine ad has appeared in a golf magazine. But it raises a larger question about whether companies choose to develop a product to address a market or what you might call a social need—do you work on a vaccine for malaria, which causes a million fatalities a year in mostly indigent populations, or do you work on a vaccine for Lyme disease, which accounts for about 16,000 well-to-do new cases a year?

Turning biological discoveries into drugs turned out to be much tougher than biotech's founders imagined, Sharp says.

SHARP: I'm enough of a realist to know that in the private sector, if you can't develop the revenues to support the technology, the technology is not going to grow. Second, you really don't bring technology to fruition, in this country and almost anywhere in the world, unless the private sector does it—because it is so difficult in large, federally sponsored programs to have the focus, the sustained *attack* that you need to develop a new pharmaceutical.

Those are constraints of the real world. There is, on the other hand, a significant amount of research being done on worldwide infectious disease problems. I suspect that commitment will grow as we increasingly learn that these diseases are very transportable. As people travel in various parts of the world and come home with the "local disease," the U.S. medical community is going to need to be able to treat them, both here and at the source, in order to control those diseases, and that in time will bring benefits.

Let me add a third point. In a recent issue of *Nature*, the British scientist Max Perutz wrote an article in which he showed that the fraction of gross domestic product being spent on biomedical research grew 10 times in the United States over the last 15 years, while growing only twofold in England and the other European countries. We have the biggest gross domestic product, and we are really dominating the biomedical research community. And as the world leaders, I think we would benefit—and benefit the world—by extending our interests a little more globally. In addition to helping people in developing places for humanitarian reasons, there are good pragmatic reasons that the government should encourage international collaborations, investments in problems and people elsewhere in the world to augment this leadership position we have. But if anything, as we've gotten more successful as a scientific community and as a pharmaceutical community, we've become more inward-looking.

TR: Given the biotech industry's historic tendency to oversell a new technology, could you provide some perspective on two of the most highly publicized recent developments, gene therapy and anti-angiogenesis as a treatment for cancer?

SHARP: I'm still very optimistic that gene therapy will emerge as a therapeutic. But it's going to take a while to learn how to use it in a clinically important way. Throwing a few genes into a patient and saying that's going to help a cancer has just not been very useful.

But there is serious work going on. I expect the first applications to emerge as vaccines, where delivering a vaccine by DNA is liable to be more efficacious than by conventional ways, and safer. That could play a role in the HIV story. And I also think that as we become capable of regulating gene activity as well as inserting genes, we're going to see gene therapy used with therapeutic genes. In other words, you'll be able to insert the gene for erythropoietin, which tells the body to make red blood cells, into the appropriate cells of a patient. And once these cells take up the gene and aren't rejected, you can essentially turn the gene on and off over long periods of time, producing a source of therapeutic protein that controls a disease state.

As for angiogenesis, my guess is that we're going to find that it's going to take four, five, maybe 10 years in the clinic to learn how to use this. And even with well-controlled experiments, you're going to step back and scratch your head and say, "Why didn't that work?!?" Or, "Why didn't it work better?" You know, like everybody else, I'd love to have it available today. But these are complicated biological processes.

TR: Do you see any danger of a public backlash against biology because of the *promise* of success—the familiar drumbeat of hype which creates the expectation that some newly discovered drug or process is going to cure disease?

SHARP: I don't underestimate the intelligence of the public. I come from Kentucky, and not from an academic family. My father was a manual laborer. I keep in pretty close contact with that community, and *they* understand now, given 20 years of intense press coverage of science, that there is always a time between discovery and delivery.

But they also, and this is very important to point out, hope that the world in the future will be better than the world in the past. And if they can't benefit from a drug, they certainly would like to see somebody else ultimately benefit from the drug. The promise that progress is being made—and historically, progress *has* been made—is something that they enjoy, appreciate and are interested in learning about. So they can dream of the day when they don't have loved ones who died of cancer. It's not going to hurt them.

It's not clear we will get there. We can't say from our technology that we're going to get there. All we can say is that we're making incremental improvements, and we would hope—and underline "hope"—that we'll get better at that.

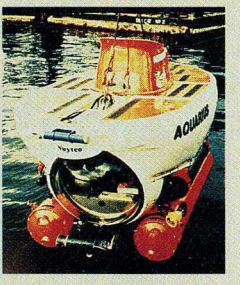
Discover...

LOUISIANA'S ATCHAFALAYA BASIN
VIA RIVER BARGE ON OUR
CAJUNS AND CREOLES PROGRAM
APRIL 4 - 12, 2000

After a day visiting New Orleans, we board the River Explorer and cruise for 7 nights through the Intracoastal Waterway traveling on America's largest fresh water swamp into the very heart of Arcadiana. Local Cajuns will be our guides as we board smaller boats to explore a part of the country few have seen—the mysterious Atchafalaya Swamp. Continue on through the Port Allen canal, which links the Intracoastal Waterway with the Mississippi, and visit Baton Rouge and the Louisiana Rural Life Museum, Laura Plantation, and Oak Alley.

Explore...

THE DEPTHS OF THE
CANADIAN ARCTIC
DURING OUR
DEEP SEA VOYAGE TO THE HMS BREADALBANE
APRIL 18 – 25, 2000



Only a handful of people have ever seen the HMS Breadalbane, a 500-ton sailing shop that sank in 1853 off Beechy Island in the Canadian Arctic. She now sits upright and well-preserved on the sea floor, 350 feet below the ice. We will travel in special submersible vehicles to view this wreck. Between dives, **Dr. James Bellingham '84**, Principal Research Engineer for MIT's Sea Grant College Program, will provide the lecture series. There also will be opportunities to view polar bears and other wildlife. Our base camp is Ice Station Beechy.

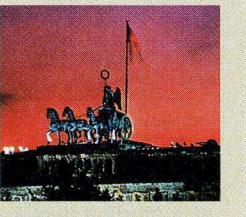
Learn...

ABOUT FLOOD PREVENTION AND ART
RESTORATION EFFORTS ON OUR
SAVING ITALY'S TREASURES PROGRAM
APRIL 25 - MAY 4, 2000

This special MIT-exclusive program will be led by MIT professor **Dr. Donald R. F. Harleman CE'50**. We will learn about Professor Harleman's important work in Venice regarding the city's battle with tidal flooding and will have the opportunity meet with local agencies charged with the protection of the city. We continue to the beautiful hill town of Assisi and meet with experts who are restoring fantastic art treasures. The enchanting town of Orvieto, perched on a crag of volcanic rock, is our next stop where we take an underground tour through tunnels buried in the tufa over 2000 years ago.

Cruise...

FROM BERLIN TO
AMSTERDAM DURING OUR
EUROPE'S GRAND PASSAGE CRUISE
APRIL 30 – MAY 14, 2000



This unique adventure covers some of the most fabled and historic inland waterways of northern Europe and the North Sea coast. We travel on board the deluxe M/S Europa from Berlin to Amsterdam, cruising the Elbe and Weser Rivers, and Dutch lakes and waterways, making stops along the way, including Potsdam, Tangermunde, Hamelin and Bremen. This program will be led by **Dr. Peter Child**, Professor of Music and Chairman of Music and Theatre Arts at MIT. The music of Bach will be a focal point of Dr. Child's lectures. He will place emphasis on what we should listen for in this sublime, complex music in order to enhance our enjoyment and understanding of it.

MIT Alumni Travel Program

MIT alumni, friends and *Technology Review* readers are welcome to participate. Please contact us for more information.
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—Peter Schechter '80 and Andrea Schechter
Alaska Family Program, August 1999

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Over 40 MIT alumni and their families (some bringing their children, others their grandchildren, and some alumni traveling with three generations) have participated on the Travel Program's family trips in 1998 and 1999. In response to growing interest for more family programs, we are offering three trips next year devoted to family travel. We hope you decide to join us for one of these superb educational programs designed for the entire family. **Call us at 800-992-6749 for further information.**

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JULY 28 - AUGUST 6, 2000

This family adventure is set against the sun, surf, sand and varied tropical landscapes of lush rainforests and lava-filled deserts. In Kauai, we learn about the natural history of the area during hiking and snorkeling excursions. We visit an active volcano at Hawaii Volcano National Park and learn about seismographic measurements and, if conditions permit, actually see red-hot molten lava bubbling up to the surface. Personal contact with local Hawaiians and special access to seldom-visited places will provide the entire family unique insights into Hawaiian culture, making this a spectacular opportunity for you, your children and grandchildren to explore and learn together.

"Our whole family agrees that the trip was memorable, really exceeded our expectations and delivered all that was promised. The staff really cared about making it great for us."
—MIT passenger
Alaska Family Program, August, 1998

Family Program to Tanzania

DECEMBER 18 - 30, 2000

What better way to see the beauty of Africa but through the eyes of your children or grandchildren? Our first visit will be to a school in the village of Sakila. Here we learn about the educational system, and the young travelers will have the chance to meet the local children and exchange addresses. At Tarangire National Park, we discover geologic landscapes as diverse as the wildlife, with nine distinct vegetation zones. Next is Manyara National Park. Finally, we travel 2000 feet down to the floor of the Ngorongoro Crater and witness the resident population of wildebeest, lions, cheetah, elephant, rhino and more. We hope you decide to join us.

family programs

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The Technology Review 100

Welcome to a special section devoted to the "TR100," 100 young innovators who exemplify the spirit of innovation in science, technology, business and the arts. Here's what our editors have prepared for you:

PROFILES. We've written concise profiles of every one of the TR100—the most remarkable group of innovators under 35 ever assembled. We've divided the profiles into five groups corresponding to the subjects that are most frequently covered in *Technology Review:* **Software, Biotechnology, the World Wide Web, Materials Science, and Hardware.** Each profile tells you, cleanly and crisply, why this is an innovator to watch.

TRENDS. Once we'd assembled the TR100, we realized that this group of brilliant young people are better positioned than anyone else to see the future of technology. So we used their amazing brainpower to answer a top-of-mind question: What are the most important technological trends of the next decade? We've summarized their answers in each of the five technology areas.

THEMES. As we profiled the TR100, two themes emerged repeatedly: the increasing scale of technology collaborations, and the growing ease with which innovators move between academia and the private sector. Two short pieces highlight these themes.

HOW WE DID IT. We rounded this special section off with a story that takes you behind the scenes and lets you in on how we picked the winners, identifies our distinguished Panel of Judges, and offers you an alphabetical index of the entire TR100.

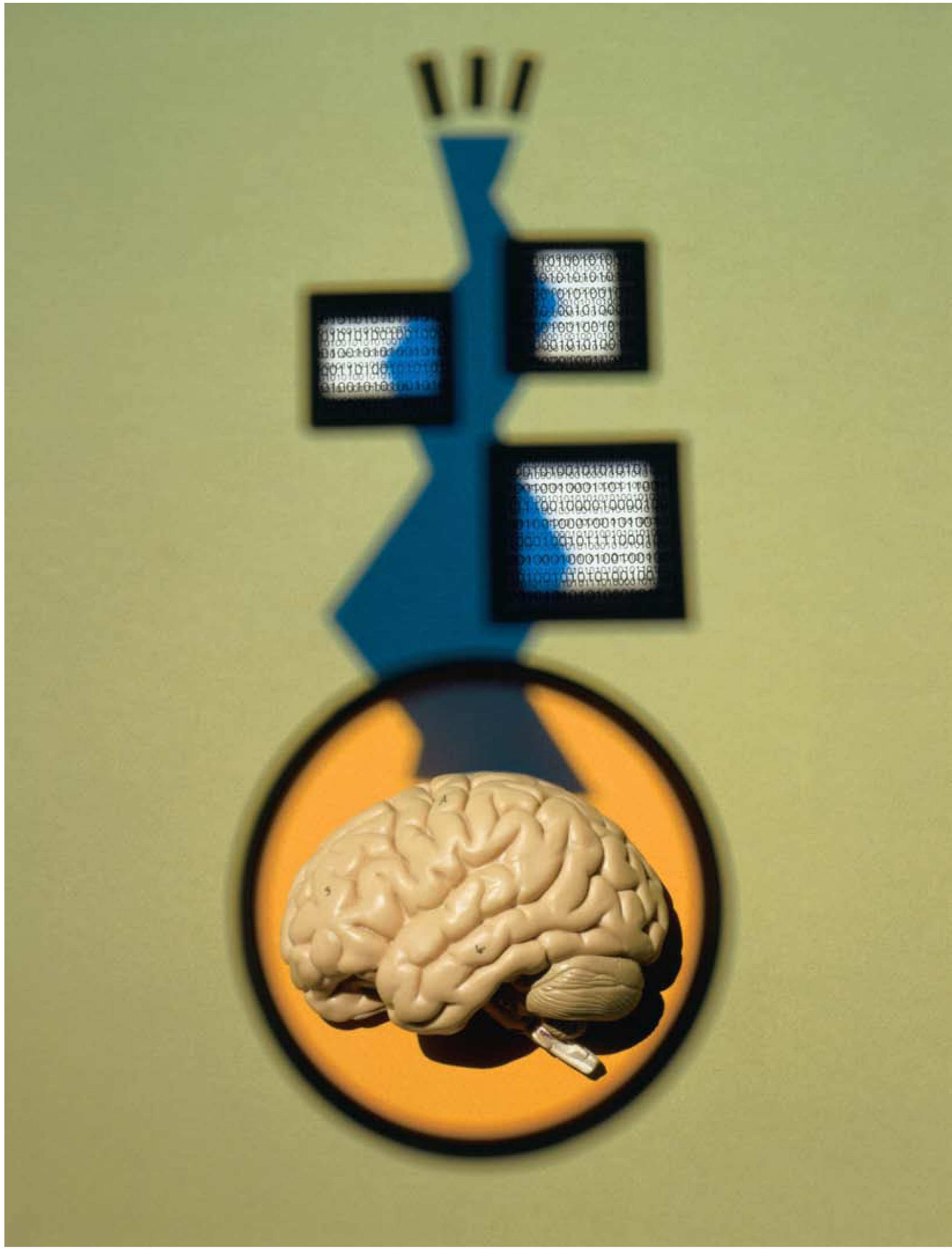
PHOTO-ILLUSTRATIONS BY PIERRE-YVES GOAVEC

Software

YOU MIGHT THINK SOFTWARE IS IN FOR A RELATIVELY PLACID FUTURE COMPARED with hardware or the Web. Sure, there will be higher version numbers and new features, but you might assume that there won't be any advances as revolutionary as the leap from the calculator to the spreadsheet or from the typewriter to word processing software. The TR100 say: Guess again. Big changes are coming in the next decade, they predict, affecting where software resides, whether we can tinker with its source code ourselves, how complex it is, and how we interact with it. These changes could make computing in 2010 more accessible and reliable than can easily be imagined today.

Complexity Crisis

ONE REASON THE TR100 FORECAST SHARP CHANGES IN SOFTWARE is that they think today's consumer software is mostly pretty bad. Not only that—software, they say, is actually getting worse, as commercial designers add bell after bell and whistle after whistle with little concern for what happens at the average user's keyboard. "There's been a serious decrease in the quality of software people are running, as complexity has increased," says **Paul Kocher**, head of Cryptography Research. Computer vision researcher **Michael Acheson Isard** of the United Kingdom agrees: "As computers get faster, the applications people use from day to day continue to run at the same speed, or slower, and incompatibility forces people to continually upgrade to newer versions, often against their will."



Many of those interviewed stressed that greater simplicity and design elegance is central to cleaning up this software mess. Kocher cites Java as a good example of what's needed more widely. "Make the system as simple as possible, use small amounts of high quality code—the Java model tries to do this." **Eric Brewer**, chief scientist of Inktomi, sees the move to simplicity manifested in specialized devices like the Rio MP3 music player—which has its own very simple operating system. Although these computing devices do only one thing, they do it well—a trend consistent with what the TR100 saw happening in the Internet space *(see p.102)*.

Open the Books!

PERHAPS THE MOST RADICAL METHOD OF INCREASING THE SIMplicity and elegance of software design is to take it out of the hands of big corporations altogether—and give it back to the community of hackers. That's the goal of the "open source" software movement, which the TR100 believe will be of great significance in the decade to come. Major open-source software is written by large collectives of hackers, collaborating over the Internet and fixing each other's mistakes. The product is distributed free of charge, and those who use it are free to look at the source code. Open-source software offers two antidotes to the epidemic of complexity: The software's components have been thoroughly tested before they're used, and, if bugs crop up, they can be fixed in-house, because the source code is available.

These features will make open-source software resonate through the early part of the next century. Until now, however, the Linux operating system, the most heralded outcome of the open source movement, has been the province of serious programmers only. Packaging it in a more accessible form with new PCs may help to change that. The GNOME project, spearheaded by TR100 member **Miguel de Icaza**, aims to make a big difference and get free software onto everybody's PC *(see "Programs to the People," TR January/February 1999)*. GNOME offers an intuitive interface (written collectively, of course) for high school students and everyday end-users. In speaking with *TR*, de Icaza displayed an intriguing combination of self-effacement and self-esteem. On the one hand, he acknowledged repeatedly that he was "very biased" in assessing GNOME. But lots of developers, investors and analysts agree with one of his "biased" predictions: "My project is going to kick ass!"

David Gee, who started IBM's alphaWorks online research lab, says the future may lie in a combination of open-source and proprietary approaches. Corporations may use an open-source operating system and Web server (Linux and Apache, another open-source OS, are now supported by IBM), but, "for other software—corporate customers are looking for stability and someone to turn to for features and functionality. Databases, transaction-processing software, messaging, Web application serving, office productivity tools, and so on, require support and development and availability in numerous countries and languages," says Gee. "This is not a strength today of the open-source model."

The Network Is the Software

WHETHER THE SOFTWARE OF TOMORROW IS OPEN-SOURCE OR MADE on the Microsoft model, it may well undergo another sea change, say the TR100: departing the user's desktop for the Web. Hotmail has already scored success by implementing this concept for e-mail. **Eric Freeman**, interface designer and CTO of Mirror Worlds, says other examples are out there. "Many of the online portals are providing e-mail, file storage, and PIM [Personal Information Management] capabilities all from the Web," he said. "Essentially they are replicating the desktop. I think already there are a great many users who spend more time on the Web than on their desktops." GNOME's de Icaza says he expects desktop software to remain important, but the Web approach allows more rapid updates to software, without the need for the user to do anything. (His project's GNOMEMail will soon offer a Web interface to e-mail.)

Speaking to Software

THE DISAPPEARANCE OF THE "DESKTOP" AND THE APPEARANCE of the "Webtop" might not be the biggest change we experience in software in the near future, according to the TR100. Perhaps the most dramatic change will be that we won't type our commands—we'll simply speak them. "Speech is the most natural and efficient form of human communication," argues AI researcher **Lawrence Saul** of AT&T Labs. "It remains a great scientific and technological challenge to understand how humans recognize speech and to mimic this ability in machines. Meeting this challenge will unleash a new era in man-machine communication." Will the challenge be met soon? "I certainly think speech recognition will arrive in this decade in a big way," says Eric Brewer. IBM's Gee agrees, naming speech recognition as the next decade's single biggest breakthrough. And it will come none too soon, he claims, since "we are making major advances, but we still don't have the relationship with the computer that allows us to talk and receive intelligent responses."

Although the TR100 think talking to machines will be very important in the near future, they don't necessarily think its largest impact will be on the PC—or that it will make the keyboard obsolete. The major use of the talking interface, they told us, will be in systems that are nothing like a desktop computer. , an AI researcher at Mitsubishi Electronic Research Labs, looks to the Japanese cellular phone market, where interfaces for tiny devices are already cumbersome. "Perceptual interfaces, particularly those that interpret speech and visual gesture, will come to dominate as devices become too small to have keys and buttons," he said.

But as in the other areas of technology, what gives us freedom can also take freedoms away, and several of the TR100 expressed concern about new interfaces that track human speech and gesture. Isard says that in a few years machine-vision systems may well be able not only to detect people, but also to "give a good estimate of whether or not those people are acting 'suspiciously.'" Isard expressed concern about potential abuses, citing a camera now being used in the United Kingdom to record the license plate numbers of all passing cars. Kocher of Cryptography Research mentioned similar cameras in the United States. Combined with computers and increasingly intelligent software, the cameras could automatically recognize license plate numbers and identify the car's owner. "The FBI's attitude is that if it's not illegal, we should do it. If it is, we should get the law changed," says Kocher. And that's an attitude that worries some of the TR100 a lot. TR

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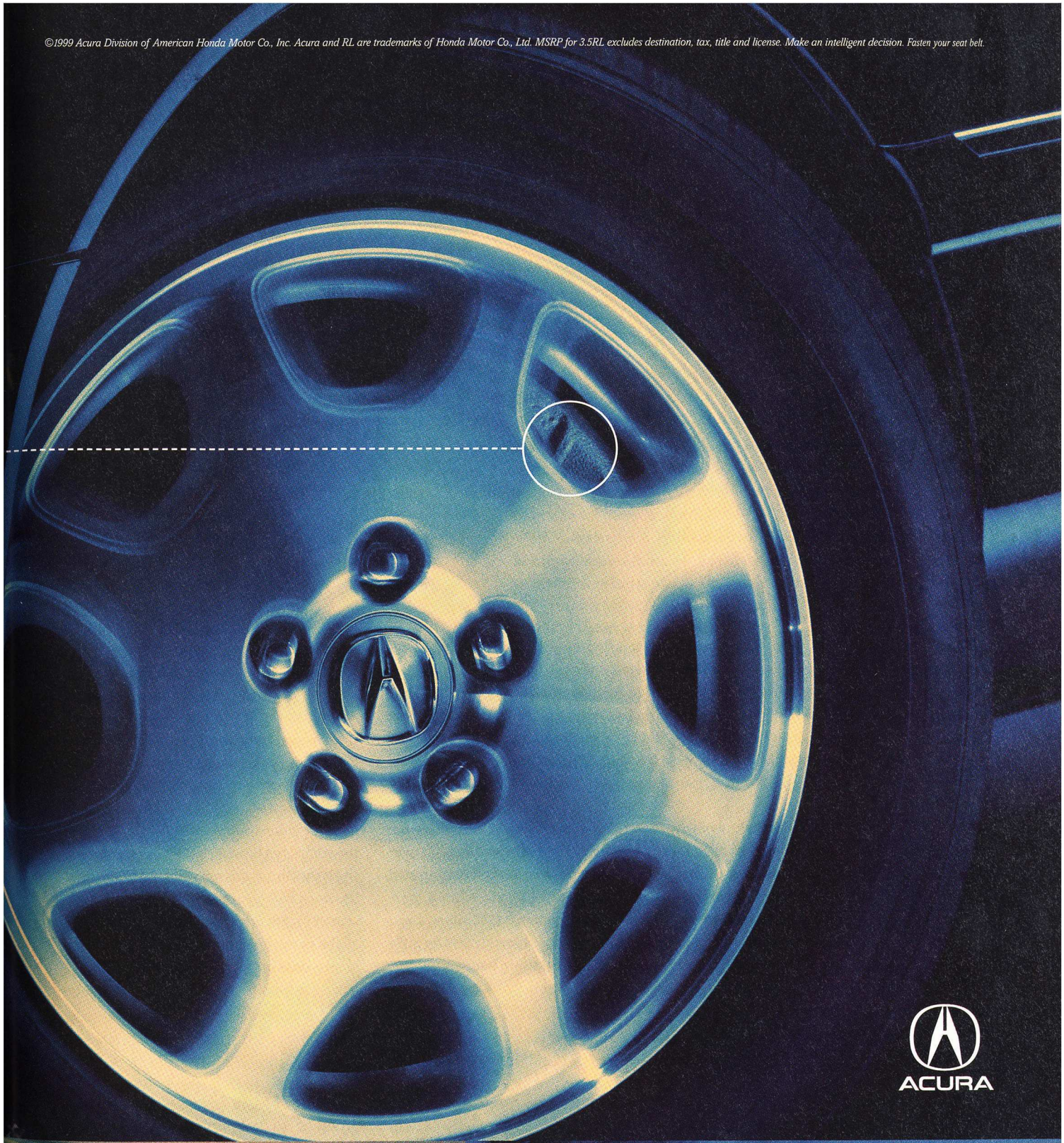

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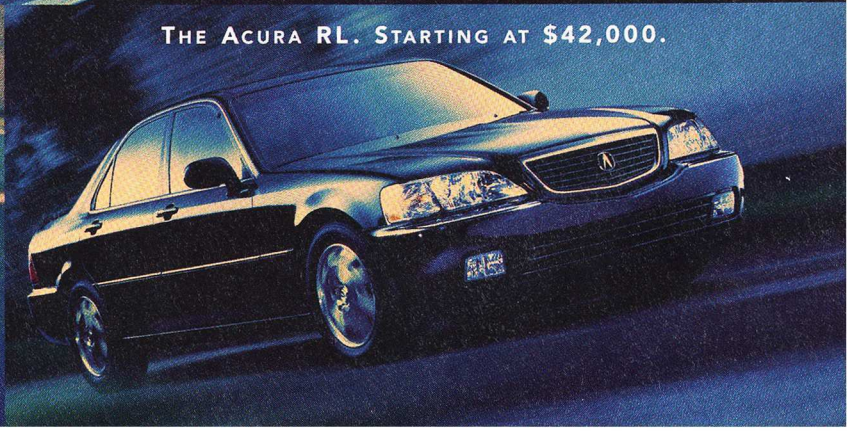
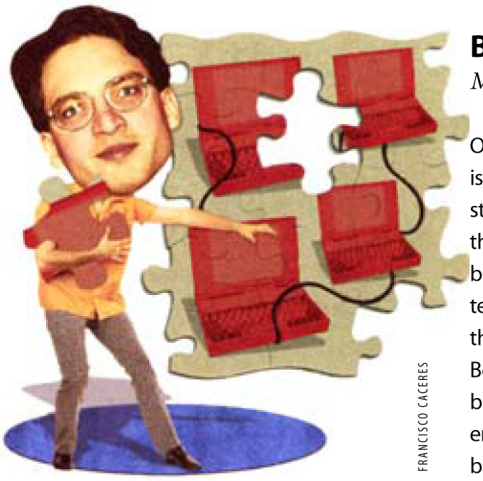


ADAM L. BEBERG, 25

Cosm



FRANCISCO CACERES

Some computational problems, such as defeating today's commercial encryption, strain even the most powerful machines. Adam Beberg has figured out how to tackle such challenges: Throw the unused time of 10,000 computers at them. Such "distributed computing" promises greater access to number-crunching power, possibly leading to scientific and technological breakthroughs. For example, SETI@home, a search for intelligent life in the universe, is following Beberg's lead with a distributed computing scheme to analyze radio telescope data. In a realm with more commercial significance—encryption—Beberg's ideas have already paid off. In 1997, he founded a nonprofit group called Distributed.net. During the group's first year, it hosted an alliance of computers called the Bovine Cooperative, which won a prize by breaking a form of encryption known as RC5. Beberg left Distributed.net in April to work on Cosm, an open-source distributed computing project. Says former colleague Michael Labriola, now CEO of Invisible Web Publishing: "The ideas that came intuitively to him could literally change the world."

DAVID BLUNDIN, 32 *DataSage*

The ballooning volume of information available through the Web and other media presents a problem: How do we make sense of all that data? Businesses are particularly hungry for tools to sift massive amounts of information to yield nuggets of insight about their customers' behaviors and needs. Such "data mining," which involves a blend of marketing techniques, innovative software, graphic design and other disciplines, is just now finding the strategies that work. It may be one of the most important economic realms of the next century—and David Blundin, founder and CEO of DataSage, is likely to be a key innovator.

Venture capitalist Duncan McCallum of One Liberty Ventures calls Blundin "the most visionary person I have ever met" in the field of decision-support software. "Dave has established an impressive track record of leading and commercializing groundbreaking innovations in data mining, particularly its application to customer intelligence," McCallum says. Blundin, he adds, has "the ability to spot important trends and an ability to create novel solutions to problems." As retailing becomes e-tailing, this is someone to keep an electronic eye on.

BONNIE BERGER, 34

MIT Laboratory for Computer Science

One of the "grand challenges" facing biologists is predicting the complex three-dimensional structure of proteins. The kinks and folds in these large molecules largely determine their behavior; certain combinations of coiled proteins in virus membranes, for example, allow the virus to insinuate itself into a cell. Bonnie Berger is leading a group of computational biologists to develop software that uses mathematical algorithms to predict protein folding based on the sequence of amino acids. Such insights could eventually lead to new drugs to combat viral disease such as AIDS. Her lab is also tackling the problem of gene identification: devising software that can help indicate where in the mind-numbingly vast strings of DNA sequences (most of which are random filler called introns) lie the bits and pieces of actual genes that carry the blueprints for proteins.

DONNA COVENEY

Berger started out as a computer scientist and applied mathematician. But as an MIT postdoc looking for ways to apply the algorithms she was devising, she found that it was the biologists who gave her some of the most interesting problems. So she took some courses in biochemistry and, she says, "picked up biology on a need-to-know basis." Moving from computers and mathematics to biology, she admits, has brought on "culture shock." But she is thriving in this mixed milieu. "Her work has been highly innovative and important," says MIT math professor Daniel J. Kleitman—all the more remarkable, he says, because "it is very unusual for a computer scientist to make a recognized impact in biology."

MATTHEW BRAND, 33 *Mitsubishi Electric Research Labs*

Matthew Brand studies mathematical approaches to learning and perception. That may sound dry, but, in fact, you may soon be seeing Brand's work at a movie theater near you. The reason? His research leads to the creation of "digital puppets" that incorporate not just the appearance but also the mannerisms of movie stars. Brand moves easily between academic research and the private sector, but in both settings his persistent theme is designing computer systems that understand and interpret three-dimensional reality. In his research at MIT's Media Lab he built an "artificial artist" that designed mobiles. This synthetic Calder combined computer vision methods for accumulating images with AI software that enabled it to pick out the most relevant features of each image.

After studying at MIT and teaching at Northwestern, Brand moved to the Mitsubishi Electric Research Labs in Cambridge, Mass., where he focuses on entertainment applications. He has developed a puppet that uses a voice interface (a face animated by speech input) and one driven by shadows. "Early adopters will most likely use this technology to synthesize people—historical, contemporary, or even nonexistent," says Brand. As such technology permeates Hollywood, it may create a new type of cinema for the 21st century.

ERIC BREWER, 32 *Inktomi*

One way for a search engine to cope with the Web's explosive growth is to employ a cluster of cut-rate computers, since more machines can easily be added to keep pace with increasing demand. Eric Brewer took this scalable approach in forming Inktomi, a startup that went public (very lucratively) last year. Brewer straddles academia and entrepreneurship; the technology underlying Inktomi was developed with one of his computer science students at the University of California, Berkeley. Inktomi's system not only scales up easily, it can also keep running in the face of massive processor and disk failures—qualities that have persuaded HotBot, FindWhat and other Web search engines to use Inktomi technology. Recently, Brewer has led Inktomi to develop the Directory Engine, which for the first time allows a Yahoo-like catalog to be built and maintained automatically, after humans set up categories and put sample documents in place.

Wearing his academic hat, Brewer designed a wireless system, GloMop, that enables handheld devices to draw computing power and network access from a stationary machine. "Brewer is one of the rare individuals who has the analytic, design and experimental skills required to make a truly great computer systems innovator," says Berkeley computer science professor Randy H. Katz. Internet search engines and wireless communications will be two of the hottest information technologies in the coming years—and Eric Brewer is at the leading edge of both.

ERIC FREEMAN, 34
Mirror Worlds Technologies

The desktop metaphor that has dominated (and limited) computer software for more than a decade may face its first major challenge from Lifestreams, an operating system environment that began as Eric Freeman's doctoral thesis at Yale. Lifestreams relies on a different visual metaphor, presenting e-mail, schedules, online feeds and so forth as a chronologically arranged stack of documents, all automatically captured and easily reorganized on demand. The idea was granted a patent this year. Freeman stands out for the boldness of his vision. "His choice of thesis topic showed considerable nerve," says computer scientist David Gelernter, Freeman's advisor at Yale. "It was risky—a radical departure and not an incremental improvement. He thought he could bring it off and he did."

GALE ZUCKER

In 1997, Freeman and Gelernter cofounded Mirror Worlds Technologies (the name plucked from a Gelernter book on future computer interfaces). Their goal: interfaces, software architectures and tools for managing electronic information. With Freeman as CTO, the company has introduced its first product: Lifestreams Office. Now comes the hard work of convincing information technology managers that this is indeed a better mousetrap. With a foot in the private sector, Freeman is maintaining academic ties; he was recently named a fellow at Yale's new Center for Internet Studies.

MANDY CHESSELL, 34 *IBM UK Development Laboratory*

God toppled the Tower of Babel, and prevented the human tribes from speaking a single language. Something similar might have happened to the equally presumptuous computer revolution if it weren't for middleware—software that enables disparate programs to talk to one another.

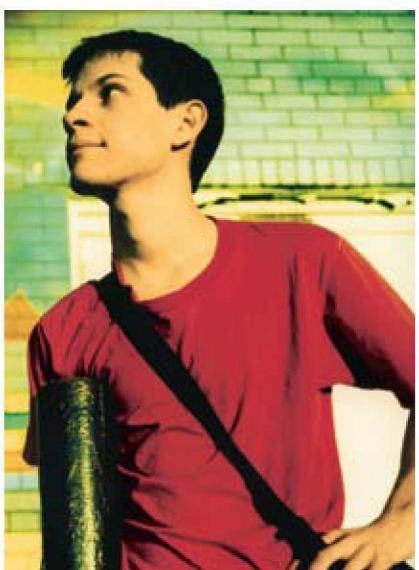
Middleware is big business for companies such as IBM; hundreds of programmers labor at the UK Development Laboratory in Hursley Park to create Big Blue's latest offerings for the enterprise market. One rising star is Mandy Chessell, a software developer who says she was first captivated at 17 by computing's strange combination of "logic and creativity." Those are terms that IBM Distinguished Engineer Tony Storey says apply to Chessell herself: "She's a constant source of innovative ideas." Chessell's name appears on 14 filed or issued patents.

Chessell's most important project is the code behind Component Broker, a new middleware system that has been bought by companies such as Charles Schwab. Chessell's work is crucial as companies move to launch new services, often on the Internet, and need to connect their "legacy" systems to new software.

MIGUEL DE ICAZA, 26 *GNOME Project*

Geeks love Linux—the "open-source" operating system that, amazingly, might pose a serious threat to Microsoft Windows. But the rest of the world—say, 99 percent of us—have little patience with Linux's arcane command-line interface, which seems like something out of the bad old days of DOS. The solution? Give Linux an easy-to-use graphical interface, designed, naturally, as open-source software. That project, already well under way, is led by Miguel de Icaza in Mexico City.

De Icaza is coordinating development of a graphical interface called GNOME that makes Linux accessible to all by giving Linux the windows and icons that the masses have become accustomed to. (The system is free for the download.) In addition to spearheading GNOME, de Icaza has developed an open-source spreadsheet program called Gnumeric—impressive accomplishments for a mathematics undergraduate at the National University of Mexico who holds a day job at the school as a computer systems administrator. Richard Stallman, the MIT open-software guru, calls de Icaza "not only a capable software designer, but an idealistic and determined campaigner for computer users' freedom."



ANN STATES

DAVID GEE, 32

IBM

The turnaround in IBM's fortunes led by CEO Louis Gerstner would have been impossible without grass-roots agents for change like David Gee. Under Big Blue's old regime, innovation was often stifled by a reluctance to embrace and exploit ideas from outside IBM. Gerstner let in new blood. Gee joined IBM in 1995 from Dun & Bradstreet, soon establishing himself as a proponent of an emerging Sun Microsystems technology: Java. This platform-independent computer programming environment, now the lingua franca of the Internet, has been a cornerstone of IBM's successful push to make itself an e-business behemoth.

In managing IBM's Java initiative, Gee was responsible for "building a team, working with customers, developers, analysts and influencers the world over, and truly establishing IBM as a leader in open standards and e-business," notes Mike Lawrie, general manager of IBM's operations in Europe. Gee also managed alphaWorks, IBM's online research lab, which promotes new Internet technologies (mostly Java-based). His evangelizing proved so effective that IBM now has more than 3,800 Java professionals developing applications—an effort on a par with Sun's.

Earlier this year Gee was given a vote of confidence with a new position in Paris as Lawrie's executive assistant, a job title often on the fast track for joining IBM's top management ranks. Could Gee be an eventual successor to CEO Gerstner? You read it here first.

PEG SKORPINSKI

JOE HELLERSTEIN, 31

University of California, Berkeley

Those who devise efficient ways to cut through "data smog" will be much in demand in the future. Among that group, one name to keep in mind is Joe Hellerstein of the University of California, Berkeley. Hellerstein's work lies in finding the best way to put information into databases and then get out what you want—and nothing else. Some of his database-related contributions include CONTROL (Continuous Output and Navigation Technology with Refinement On-Line), an approach that exploits continuous user feedback to refine the action of a search engine, and GiST (Generalized Search Tree), a way of finding answers to questions without having to worry about the type of data in the answer. Jim Gray, manager of Microsoft's Bay Area Research Center, calls Hellerstein "the most promising of his generation of database systems scientists."

Although working at a research university, Hellerstein is also pursuing commercial applications. He has designed Cohera DFS, a system intended to manage the computing resources of a large enterprise. Hellerstein is also on the technical advisory board of MySimon, a Web-based shopping service that provides inventory and price information from a large array of Web sites. Work like Hellerstein's offers hope that today's data smog will dissipate in tomorrow's information daylight.

MICHAEL ACHESON ISARD, 28

Compaq's Systems Research Center

For a human or a bird, the task is trivial: visually track an object moving through a cluttered scene. But computer vision can't do this—there are too many visual ambiguities for even the most advanced artificial intelligence programs. Michael Acheson Isard is working to get past these obstacles. For his doctoral thesis at Oxford, he devised an algorithm called CONDENSATION, for CONditional DENSity PropagATION. Isard's thesis supervisor, Andrew Blake, says Isard's technique promises a "revolution in the design of intelligent machines." The premise is that as a computer watches a scene, it must continually reweigh alternative interpretations of what is signal and what is noise—mimicking human visual perception. Isard's work, says Blake, has "sparked a whole new area of activity by other researchers."

This fall, following a three-year postdoc at Oxford's Magdalen College, Isard took a research position at Compaq's Systems Research Center (SRC) in Palo Alto. According to Blake, this Anglo-American, born in England to American parents, is "set to have a major impact on the way machine intelligence develops over the next decade."

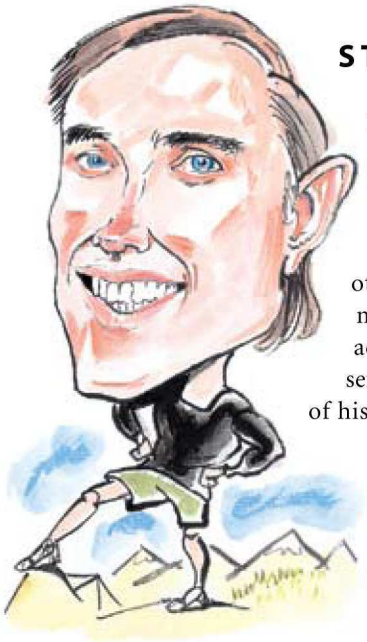
CHARLIE POWELL

CHRISTINA JONES, 29 *pcOrder.com*

In selecting the TR100, we looked for folks who keep innovating even after they've had one triumph. Christina Jones fits that description. She has already had one major success in Trilogy, the $100-million-a-year front-office software company she founded in 1996 with fellow Stanford student Joseph Liemandt and three other young partners. But Trilogy seems to have been just a start.

Some of Trilogy's software coordinates the configuration of multitudes of interchangeable parts in computing systems. Jones realized that PC makers and distributors could use this technology to facilitate sales of made-to-order PCs—a booming business now dominated by Dell. Jones thought there was room for others in that market, however, particularly with Trilogy's software as a way to improve efficiency. To start her new company, pcOrder.com, she sold her Trilogy stock back to Liemandt in exchange for access to technology and some financial support.

Dell's growing market share means its competitors will be looking for an edge—creating a niche for pcOrder's products. Indeed, Compaq, Hewlett-Packard and IBM have already licensed pcOrder software.



DAVID SMALL

STEVE JURVETSON, 32 *Draper Fisher Jurvetson*

His line of work is venture capital, but "adventure capitalist" might be a better way of describing the managing director of Draper Fisher Jurvetson, a Silicon Valley firm that's at the heart of the Web frenzy. Jurvetson has repeatedly shown his ability to recognize young entrepreneurs who can deliver. Examples: Sabeer Bhatia *(see p. 106)* and John Smith, co-founders of Hotmail, the free Web-based e-mail site. More than 20 other firms passed on the deal, but Jurvetson's firm plunked down $300,000 on Hotmail. The move paid off when Microsoft bought the company for a staggering $400 million. Jurvetson achieved another notable success with his investment in Four11, a free e-mail and directory services company. A classic overachiever, Jurvetson graduated from Stanford at the head of his class in just two and a half years, and made partner at his firm after six months. He shows no signs of slowing. In mid-1999, Jurvetson was financing no less than 11 companies ready for public offering.

PAUL KOCHER, 26
Cryptography Research

Can you keep a secret? Paul Kocher can. As a leading cryptographer, he is helping make the Internet safer for business transactions and personal information. As more business is conducted on the Net, the need for online privacy grows apace. As a result, cryptography—making and breaking codes—is becoming central to the Web's further development. Paul Kocher is among the handful of people who are making significant contributions. Among Kocher's accomplishments is the formulation of a method to defeat RSA encryption, one of the most widely used forms of securing transactions. (Breaking existing codes is part of a cryptographer's job description.) He is also one of the designers of the Secure Sockets Layer (SSL) 3.0 protocol, which many Web sites use to encrypt and authenticate credit information.

Kocher's career shows how innovators are able to cross disciplinary lines: Although his bachelor's degree from Stanford is in biology, he taught himself everything he's needed to know about computers. He's also an entrepreneur: founder, president and chief scientist of Cryptography Research as well as co-founder and chief scientist of ValiCert. His lack of academic credentials in computing hasn't stymied his career. Says professor emeritus Martin Hellman at Stanford: "He knew more than most people who had completed PhDs in the area. When people call me for consulting, Paul is my first recommendation."

CHRISTOPHER KLAUS, 26
Internet Security Systems

Computer security is a little like the War on Drugs—you catch as many perpetrators as you can, but you never catch them all. As more and more of the economy goes online, the stakes are rising—and anyone offering a better form of Internet security deserves attention. As the founder and chief technology officer of Internet Security Systems (ISS), Christopher Klaus is at the forefront of those peddling peace-of-mind.

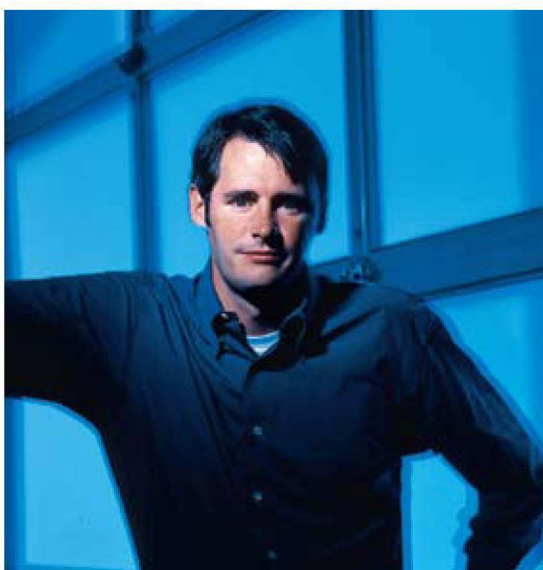
Klaus has been noodling with computers for most of his life—at 9, he was programming games on his Commodore 64. Klaus' most ingenious creation is the Internet Scanner, a software package from ISS that uses hundreds of tests to probe a network's vulnerability, analyze security weaknesses and recommend solutions. Klaus released his first version as shareware while he was an undergraduate at Georgia Tech. Internet Scanner has won several awards as the best Internet security product of the year. The pervasive angst about computer security has been very good to Klaus: Forbes estimates his net worth at $187.5 million.

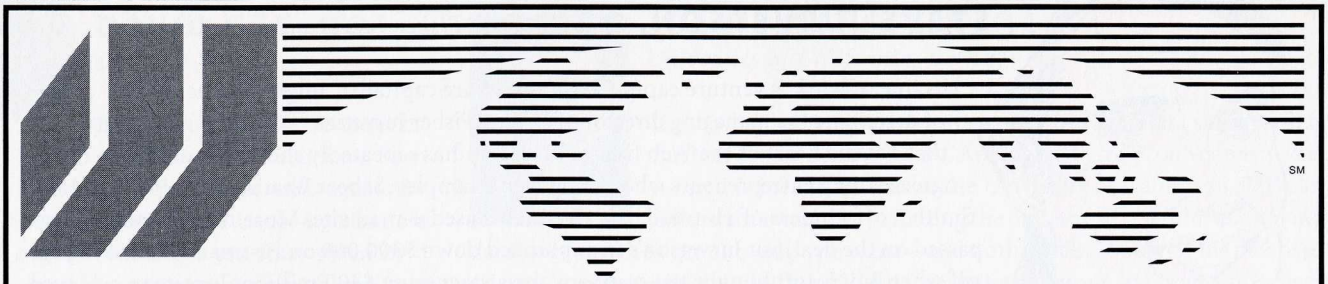
MIKE MCCUE, 33 *Tellme Networks*

Mike McCue has the distinction of being indirectly responsible for crashing a large chunk of the Internet. Not on purpose, of course. The company McCue founded in 1990, Paper Software, created a VRML (virtual reality modeling language) plug-in that enabled the Netscape Navigator browser to display complex graphics. Paper Software's site was inundated by people seeking to download the program. This development naturally caught the attention of Netscape, which put Paper Software's Web site on its home page. The resulting overload temporarily brought down a large portion of the Northeastern Internet hub.

Most of the outcome, however, was positive. The fuss attracted the attention of Netscape co-founder Marc Andreessen *(see p. 106)*. McCue, who had turned down offers from America Online and Silicon Graphics, sold his company to Netscape, where he became director of advanced technology. After the announcement of Netscape's imminent acquisition by AOL in 1998, McCue left to start Tellme Networks. Tellme won't tell us exactly what it's up to, but it's rumored that the company will make a natural-language interface for accessing the Web with speech over the phone.

JAMES PATRICK DAWSON





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$10,000,000,000 Healtheon *has agreed to merge with* WebMD *Pending*	*$3,700,000,000* INS International Network Services *has agreed to merge with* **Lucent Technologies** *Pending*	*$1,700,000,000* EXCEL *has agreed to be acquired by* **Lucent Technologies** *Pending*	*$1,650,000,000* EDS *has agreed to acquire* **MCI Systemhouse** *Pending*	*$1,100,000,000* Data General *has agreed to be acquired by* **EMC** *Pending*	*$810,000,000* SEQUENT *has agreed to be acquired by* IBM *Pending*
$720,000,000 Transaction Network Services, Inc. *has agreed to be acquired by* **PSINet, Inc.** *Pending*	*$700,000,000* SAVILLE *has agreed to be acquired by* **ADC Telecommunications, Inc.** *Pending*	*$677,000,000* i-Cube Transforming the Business World *has agreed to merge with* **Razorfish, Inc.** *Pending*	*$552,100,000* Excite@Home *has agreed to acquire* **iMall, Inc.** *Pending*	*$460,000,000* Healtheon *has agreed to acquire* **MEDE AMERICA Corporation** *Pending*	*$419,500,000* First Data Corp *has agreed to acquire a 45% stake in* **Paymentech** *Pending*
$340,000,000 Chemdex Accelerating Science *has agreed to acquire* **Promedix.com** *Pending*	*$246,000,000* XEDIA *has agreed to be acquired by* **Lucent Technologies** *Pending*	*$215,000,000* Healtheon and WebMD *has agreed to acquire* **Medcast Networks** *Pending*	*$183,000,000* Getty Images, Inc. *has agreed to acquire* **The Image Bank** *Pending*	*$150,000,000* APPLIED MATERIALS *has agreed to acquire* **Obsidian, Inc.** *Pending*	*$2,300,000,000* AltaVista *Compaq has sold a 83% stake in AltaVista to* **CMGI** *August 19 ,1999*
$115,704,000 Getty Images, Inc. *has acquired* **Art.com** *August 5, 1999*	*$4,700,000,000* broadcast.com *has been acquired by* YAHOO! *July 20, 1999*	*$900,000,000* Nexabit Networks *has been acquired by* **Lucent Technologies** *July 19, 1999*	*$126,000,000* Microsoft *has acquired* **Sendit AB** *July 1, 1999*	*$6,300,000,000* HYUNDAI *has acquired a 60% equity interest in* **LG Semicon** *June 18, 1999*	*$83,000,000* JDEdwards *has acquired* **Numetrix Limited** *June 17, 1999*
$500,000,000 Lattice Semiconductor Corporation *has acquired* **Vantis** *a wholly owned subsidiary of* AMD *June 15, 1999*	*$1,225,000,000* VLSI Technology *has been acquired by* **Royal Philips Electronics** *June 2, 1999*	*$8,226,000,000* @Home Network *has merged with* excite *May 28, 1999*	*$1,639,000,000* Seagate Software *has merged its Network and Storage Management Group with* VERITAS *May 28, 1999*	*$2,000,000,000* XYLAN *has been acquired by* ALCATEL *April 26, 1999*	*$2,100,000,000* RELTEC *has been acquired by* **The General Electric Company, p.l.c.** *April 9, 1999*

MORGAN STANLEY DEAN WITTER

Leadership in Technology IPOs

AGILE SOFTWARE $72,450,000 Initial Public Offering August 19, 1999	SilverStream $55,200,000 Initial Public Offering August 16, 1999	HomeStore.COM $161,000,000 Initial Public Offering August 4, 1999	drugstore.com $103,500,000 Initial Public Offering July 27, 1999	Chemdex Accelerating Science $129,375,000 Initial Public Offering July 26, 1999	Ask Jeeves $48,300,000 Initial Public Offering June 29, 1999
ARIBA $132,250,000 Initial Public Offering June 22, 1999	BROCADE $71,000,000 Initial Public Offering May 24, 1999	Redback NETWORKS $66,125,000 Initial Public Offering May 17, 1999	scient $69,000,000 Initial Public Offering May 13, 1999	marimba $92,000,000 Initial Public Offering April 29, 1999	extreme networks $136,850,000 Initial Public Offering April 8, 1999

Leadership in Technology Financings

STMicroelectronics $2,450,000,000 Common Stock September 16, 1999 $1,371,562,500 Common Stock June 5, 1998	COVAD $285,000,000 Common Stock June 17, 1999	GALILEO INTERNATIONAL $1,500,000,000 Common Stock May 27, 1999	EDS $783,750,000 Common Stock May 6, 1999 $475,812,500 Common Stock August 10, 1998	CONEXANT $350,000,000 Convertible Subordinated Notes* May 6, 1999	SANMINA CORPORATION $300,000,000 Convertible Subordinated Notes* April 29, 1999
ebay $1,270,750,000 Common Stock April 12, 1999	Applied Science Fiction $31,500,000 Private Placement of Series D Preferred Stock March 29, 1999	LSI LOGIC $345,000,000 Convertible Debentures* March 15, 1999	DUPONT PHOTOMASKS, INC. $79,500,000 Common Stock March 10, 1999	EQUANT $3,574,200,000 Common Stock February 11, 1999 $810,000,000 Initial Public Offering July 20, 1998	Healtheon $46,000,000 Initial Public Offering February 10, 1999 $44,000,000 Private Placement of Series E Preferred Stock October 30, 1998
amazon.com $1,250,000,000 Convertible Subordinated Debentures* January 28, 1999 $325,987,100 Senior Discount Notes* May 5, 1998	IBM $600,000,000 Senior Notes January 27, 1999	VeriSign $254,581,250 Common Stock January 26, 1999 $48,300,000 Initial Public Offering January 29, 1998	@Home Network. $200,000,000 Convertible Subordinated Debentures December 18, 1998 $132,600,000 Common Stock August 12, 1998	ARROW ELECTRONICS, INC. $250,000,000 Senior Notes* October 22, 1998 $200,000,000 Senior Debentures May 29, 1998	BROADCOM $238,050,000 Common Stock October 20, 1998 $96,600,000 Initial Public Offering April 16, 1998
MOTOROLA $325,000,000 Notes October 15, 1998	ASPECT $150,214,400 Zero Coupon Convertible Debentures* August 5, 1998	America Online $549,780,000 Common Stock June 29, 1998	excite $85,050,000 Common Stock June 10, 1998	INGRAM MICRO $460,419,330 Zero Coupon Convertible Senior Debentures* June 4, 1998 $414,000,000 Initial Public Offering October 31, 1996	Intuit $462,000,000 Common Stock May 21, 1998
HADCO $200,000,000 Senior Subordinated Notes* May 13, 1998	JDA Software Group, Inc. $105,800,000 Common Stock May 6, 1998	DELL $500,000,000 Senior Notes and Debentures April 22, 1998	ATMEL $115,004,140 Zero Coupon Convertible Subordinated Debentures* April 16, 1998	CSG $165,080,160 Common Stock April 7, 1998	Sapient $91,200,000 Common Stock March 31, 1998

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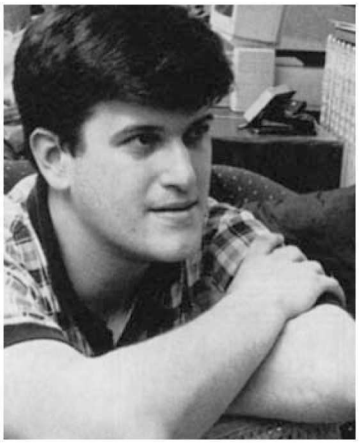
THOMAS PINCKNEY, 25
Exotec

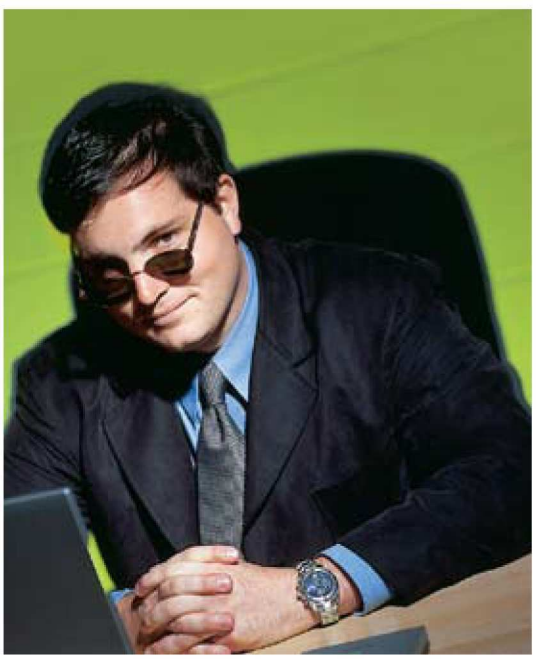


Let others perfect the programs that show up on our screens. Thomas Pinckney says he loves the invisible infrastructure—the hidden underbelly of code and tools that undergirds the information enterprise. His company, Exotec, is commercializing a novel idea for controlling how software deals with hardware. The computers we're accustomed to all use an operating system (e.g., Windows) as an intermediary. But operating systems treat all applications about the same—adequately, not optimally. Exotec is developing "exokernels," which let applications work directly with computer hardware, without letting the intermediary bog them down. The potential advantage is huge: Web servers using exokernels can operate 8 times faster than conventional ones, says M. Frans Kaashoek, who pioneered the concept at MIT's Lab for Computer Science. Exokernels let apps be all that they can be.

As a student of his, says Kaashoek, Pinckney contributed a number of "crucial" ideas about taking exokernels from research project to practicality. In 1998, smelling a market, Pinckney took a leave of absence from his PhD work and enlisted several other students to join him in forming Exotec. Initially, the cash-strapped outfit all lived and worked in an apartment in Cambridge. Pinckney evangelized the concept and landed a major customer; in September, he concluded a venture capital deal bringing his company several million dollars. Pinckney has been running on the fast track for a long time—he taught himself to program using a PC his parents gave him when he was 12, and left high school after ninth grade to enroll in a local two-year college. If exokernels take off, we'll all be on a faster track.

CHRISTOPHER J. SAVOIE, 28 *Dejima*

Many talented people are tackling the problem of developing "natural-language interfaces," to allow us to speak directly to our computers. Bicultural innovator Christopher Savoie, co-founder of Dejima, is one to watch. Currently, natural-language interfaces allow people to speak to machines using preset commands, as one might address a trained animal. Savoie, with colleague Bahrat Hodjat, co-invented natural-language interface software that will allow people to talk to machines more or less as they talk to people, with intuitive, everyday language. This technology learns from experience, and can therefore eventually resolve the conversational ambiguities that are common in speech. This combination of qualities has sparked interest from the private sector; Dejima has deals with a European telecommunications service provider as well as with a Japanese automaker.



JAMES PATRICK DAWSON

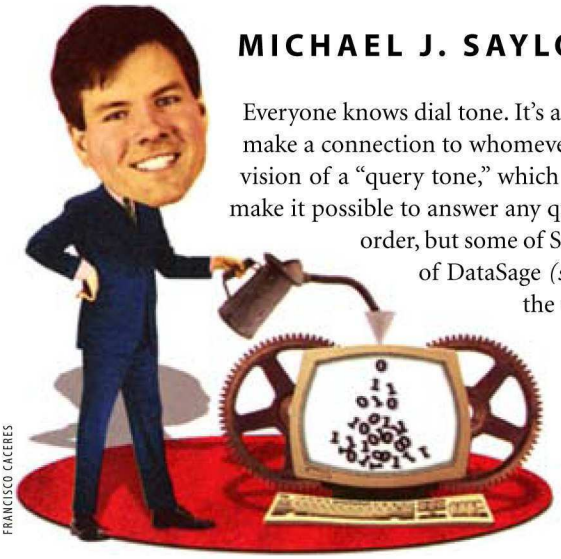
Such software might catch on first in Asia because of the problems inherent in keyboarding Chinese, Japanese and Korean. If so, Savoie will be well positioned to take advantage of the trend. He is fluent in Japanese (as well as French, Spanish and Lithuanian) and has spent a third of his life in Japan. Indeed, his two previous startups, Atmark and Webula, are Japanese companies; they do Web integration, the act of putting together the components and services necessary for a company to do business on the World Wide Web. Dejima CEO Madeline Duva characterizes Savoie as "a visionary, an inventor and a builder."

LAWRENCE SAUL, 30
AT&T Labs

Automated speech recognition has entered daily life via telephones that follow voice commands and PC-based software that transcribes dictation with 97 percent accuracy. That's good, but for many future applications, it will need to be much better, necessitating advances in the underlying technology. One example: Hidden Markov Models (HMM), the standard technique over the last 20 years. HMMs, which break speech into time-bounded units or states, don't fully reflect the variability of humans speaking.

In 1997, Lawrence Saul created a more fluid means of expressing duration in speech by plotting it as the length of a curve. The following year, Saul and a colleague at AT&T Labs used this new method to build a speech recognizer that outperformed the best HMM-based system. Michael Jordan, an expert on machine learning at the University of California, Berkeley, says Saul is doing "the most impressive new piece of work in speech recognition in many years. The improved performance he obtains is significant."

Saul graduated from Harvard with a bachelor's degree in physics, then received his doctorate in physics from MIT. Along the way he became familiar with neural networks and the computational tasks they are used to solve—a rarity for physicists. Says Fernando Pereira, head of machine learning and information retrieval research at AT&T Labs: "Larry is a pioneer in a new convergence of computer science, mathematical modeling and natural science that helps illuminate complex biological phenomena." His is a talent that requires no fancy algorithm to recognize.



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MICHAEL J. SAYLOR, 34 *MicroStrategy*

Everyone knows dial tone. It's a reliable, ubiquitous part of our world that signals us to go ahead and make a connection to whomever we want to reach, almost anywhere in the world. Michael Saylor has a vision of a "query tone," which would be a similarly pervasive service for information. Query tone would make it possible to answer any question you might have, in the form you want it, quickly and reliably. A tall order, but some of Saylor's peers in the TR100 say he's up to it. David Blundin, for instance, CEO of DataSage *(see p. 80)* says, "If you dropped Bill Gates, Larry Ellison, and Mike Saylor in the woods, naked and penniless, and said, 'First one to make a fortune wins,' I would bet on Mike Saylor."

Query tone will take decades to implement, if it happens at all. But Saylor's company, MicroStrategy, is already developing preliminary, limited versions of such a service. The company has 750 corporate clients, from a variety of different vertical industries. MicroStrategy offers them an approximation of query tone in the form of decision-support analysis via DSS Web, a Web-based product. Last year, Saylor introduced Strategy.com, billed as the world's first personal intelligence network; it allows you to subscribe to the information you want (news, weather, stock updates, and such) and specify the conditions that will trigger updates, which arrive via e-mail, fax, phone or pager. Query tone is a contender to become part of the information infrastructure. Any questions?

WIM SWELDENS, 32 *Lucent Technologies' Bell Labs*

Everybody wants pretty pictures on their screens but nobody wants to wait eons for a download, nor do they want image files to occupy their entire hard drive. Thus the critical importance of image compression—mathematical algorithms that condense visual information into the smallest possible number of bits. In recent years "wavelets" have emerged as an effective and flexible alternative to the once-standard technique known as Fourier transforms. The latest generation of wavelets are proving adept at processing three-dimensional forms such as spheres and textured surfaces. This new

mathematical framework was developed by Wim Sweldens as a postdoc at the University of South Carolina, following work on wavelets for his doctorate in applied mathematics at Katholieke Universiteit Leuven in Belgium. Sweldens, a Belgian national, has also pursued his research at Interval Research in Palo Alto.

Now a permanent resident of the United States, Sweldens has been a member of the technical staff of Bell Labs since 1995. He is now working on a signal-processing challenge in digital mobile communications—employing a matrix of antennas to turn radio interference into additional bandwidth. His research could lead to fewer dropped calls, lower battery drain on pocket telephones, and more bandwidth for wireless data transmissions. Sweldens works hard to spread the gospel of wavelets: He established and continues to edit Wavelet Digest, a monthly newsletter with 15,000 subscribers, which MIT mathematics professor Gilbert Strang calls "a key place for the exchange of news about wavelets."

LINUS TORVALDS, 29 *Transmeta*

If operating-system software has a revolutionary hero, it is Linus Torvalds. The revolutionary movement is "open-source" software—in which a system's source code is freely shared and collectively improved *(see "Programs to the People," TR January /February 1999)*. This model, which emerged from academia in the 1980s, has moved into the computing mainstream, largely due to this reticent Finn, who moved to California in 1997. Six years before, as a student in Finland, he had written his own "kernel," the core of a Unix-based operating system. In the last eight years, with the help of developers worldwide, this seed has grown to become an operating system called Linux. Linux is the world's second most popular Unix flavor (behind Solaris) and the major challenger to the hegemony of Windows. It is also being used on Internet appliances of all sizes. Even business-minded *Forbes* readers ranked Torvalds last year as their #1 Internet Hero—ahead of Bill Gates and Web creator Tim Berners-Lee.

Open source was once the province of fiery-eyed radicals. Now IBM supports it, and Oracle sells Linux products. Torvalds has moved with the trend. He remains at the center of Linux, overseeing kernel changes. But he considers the operating system a hobby. And he's got a "real" job, too: at Transmeta, a chip design company funded by Paul Allen whose work remains top-secret. A patent filed last year suggests the company's chips will be Intel-compatible. Is another revolution in store?

ANNE HAMERSKY

A salute to the

innovative spirit

of the TR 100.

(From a company that knows a thing or two about the subject.)

Innovation is what keeps Lucent Technologies and Bell Labs at the center of the communications revolution. We salute the TR 100 leading young innovators (who include three of our own best-and-brightest). With your curiosity and passion, you have the potential to change the world. (Should make for an interesting 21st century.)

We make the things that make communications work.™

Biotech

TALK TO THE YOUNG INNOVATORS NAMED TO THE TR100 FOR THEIR CONTRIbutions to biotechnology and biomedicine, and you may begin to wonder whether Lewis Carroll has been tinkering with their world. Surely, only the creator of Alice could have dreamed up the strange new cast of characters that is turning out for biotech's tea party these days. Being a mathematician, Carroll might well have spiked the guest list with others of his ilk, and also numerically minded computer scientists, engineers, physicists and businesspeople, who of course keep their eyes on the numbers as well. That's exactly what's going on in biology today, and the winners in this category reflect the field's increasingly eclectic makeup: Indeed, only half of them have degrees in biology or medicine at all.

When we asked the TR100 for a view of biotechnology's future, we got answers that took us right through the looking glass. Researchers, the TR100 say, will mine the mountain of data piled up by the Human Genome Project and other genomics efforts for new biological insights and new drugs—perhaps even paving the way for individually tailored, or "personalized," medicine. Scientists' models of biological systems may become so sophisticated that some of those new therapies will be tested in computers, rather than in lab animals or people. And already TR100 members and others are working out remarkable new ways of taking our medicine. A few more years down the line, they say, medical treatment might be an almost invisible part of our lives—think, for example, of a wristwatch-style device that monitors a diabetic's insulin level and adjusts it automatically. Finally, say the TR100, academia and business will become more and more intertwined, bringing the fruits of biological researchers' labor to the real world faster than ever before.

Information Overload

PROBABLY THE MOST SIGNIFICANT TREND IN BIOTECHNOLOGY, noted by the TR100 and by most experts in the field *(see "Mining the Genome," TR September/October 1999)*, is the accumulation of an overwhelming amount of new data, much of it coming out of the Human Genome Project. As Lawrence Berkeley National Laboratory's **Adam Arkin** puts it, the data have already "exceeded our understanding by a large fraction, and we're playing catch-up."

The chance to refine raw data into scientific and medical knowledge is precisely what many believe is drawing "outsiders" into biotech. As **Dari Shalon**, director of the Harvard Center for Genomics Research, puts it, biology is becoming an "information science" that gives engineers, physicists, computer scientists and mathematicians "something to sink their teeth into."

The information-oriented newcomers are taking their first bites in the burgeoning field of bioinformatics, generally defined as the application of information technology to molecular biology and genetics. In the past five years bioinformatics has become a hot area, and the TR100 say it will heat up even more in the next decade as genome projects wrap up. Bioinformaticists aim to build software tools to handle what the University of California, Los Angeles' **Christopher Lee** calls "dizzying" volumes of data. Lee, for example, leads a computer-analysis project that aims to scour the entire human genome looking for small genetic variations, called SNPs, between individuals. A big enough set of SNPs, he explains, should help scientists uncover the genetic components of diseases and traits, teasing out once and for all what is nature and what is nurture. Another possible outcome: potent medicines "personalized" to an individual's genetic makeup.

New Models, New Medicines

GENOMICS IS NOT THE ONLY AREA WHERE NEW INFORMATION will transform biology and medicine in the next decade, say the TR100. Indeed, a number of technologies are converging to yield more detailed data than has ever been gathered before on the operation of and interactions between individual cells. The payoff in basic science is obvious: better models for understanding how something like the immune system or the brain functions. The technological payoff is harder to pin down, but TR100 members offer at least one radical possibility: using sophisticated computer models to test drugs and medical interventions "in silico," rather than in expensive lab and animal experiments.

On the basic-science side is the University of Texas' **Jason Shear**, who is capitalizing on recent developments in microscopy, fluorescent dyes and chemical analysis to observe neurons as they interact. Shear is building an instrument to peer down into the neurotransmitters released at synapses. He believes measurements on this scale will uncover details that may be key to solving some of biology's biggest riddles, such as memory's chemical basis.

Shear's efforts are in their early stages, but TR100 members see the intensity of this type of work growing quickly. "In the next five to 10 years," predicts Arkin, "we'll have amazing measurement equipment, capable of following thousands of variables with great temporal resolution, cell- and system-wide." The result, he adds, is that researchers may have "enough data for the first time to put it back together in dynamic computer models of how it all works." And that, in turn, should enable scientists to perform computer simulations that accurately gauge the effect of new drugs—before ever testing them on a person.

Engineering Drug Delivery

ALL OF BIOTECH'S NEW MEANS OF GENERATING AND TESTING drugs, however, will only intensify the need for better ways of delivering them. That's because, as **Mark Prausnitz** of Georgia Tech puts it, "the better the drug, the more complex the molecules—and the harder it is to deliver." So medical researchers are quickly teaming with engineers to confront the drug-delivery problem. The coming years, say the TR100, should see a range of ingenious methods—from micromachined implants to ultrasound and electricity—for getting medicines into our bodies.

Sontra Medical's **Samir Mitragotri** explains that these drug-delivery systems will be designed specifically with an eye toward creating a "smoother and smoother interface between medicine and life," and delivering treatments without pain, nuisance—or even any intervention by the patient. His own aims include, for example, a patch or wristwatch that monitors a diabetic's blood sugar level and automatically delivers the appropriate level of insulin, without finger-sticks or injections.

Though Prausnitz, Mitragotri and others have already made dramatic inroads in drug delivery, fundamental challenges remain. The University of Illinois, Chicago's **Tejal Desai**, for example, points out that some bioengineers have begun using silicon-based fabrication techniques from the microelectronics industry in building new drug-delivery devices. While that allows them to address problems on a biological or single-cell scale, Desai says, it also requires that they use materials our bodies aren't used to. "We can make these nifty microstructures in silicon," explains Desai. "But can we do it with materials that might be more appropriate for the body?" Developing better materials for drug-delivery vehicles, biosensors, implants and other bioengineered devices will be a key area of work in the next decade.

Biology, Meet Business

MANY OF THE TR100 BIOINNOVATORS STRESSED THEIR BELIEF that the growing fluidity between fields will be critical to biotechnology's future success. The problems in biotech, they told us, are too large for any one individual, laboratory, or even discipline, to tackle. What's more, they believe the future will bring an even tighter connection between industry and academia, in large part because industry has the resources to make ideas reality. "If your work is valuable, then you're going to want to get it out there into as many hands as possible," says Johns Hopkins University's **Patrick Jensen**.

The increasingly intimate contact between science and business opens opportunities for researchers who, like many of the TR100, have some savvy in both areas. Shalon is a good example: Just out of school with a freshly minted PhD he founded a DNA-chip company named Synteni. Less than five years later, he sold it for $90 million and accepted the position at Harvard, which will put him in charge of 50 or 60 full-time researchers—at the ripe old age of 34. No wonder, then, that Shalon believes "this next century is going to be the golden age of biological science." We think the people you're about to meet in the next few pages will be instrumental in making it so. TR

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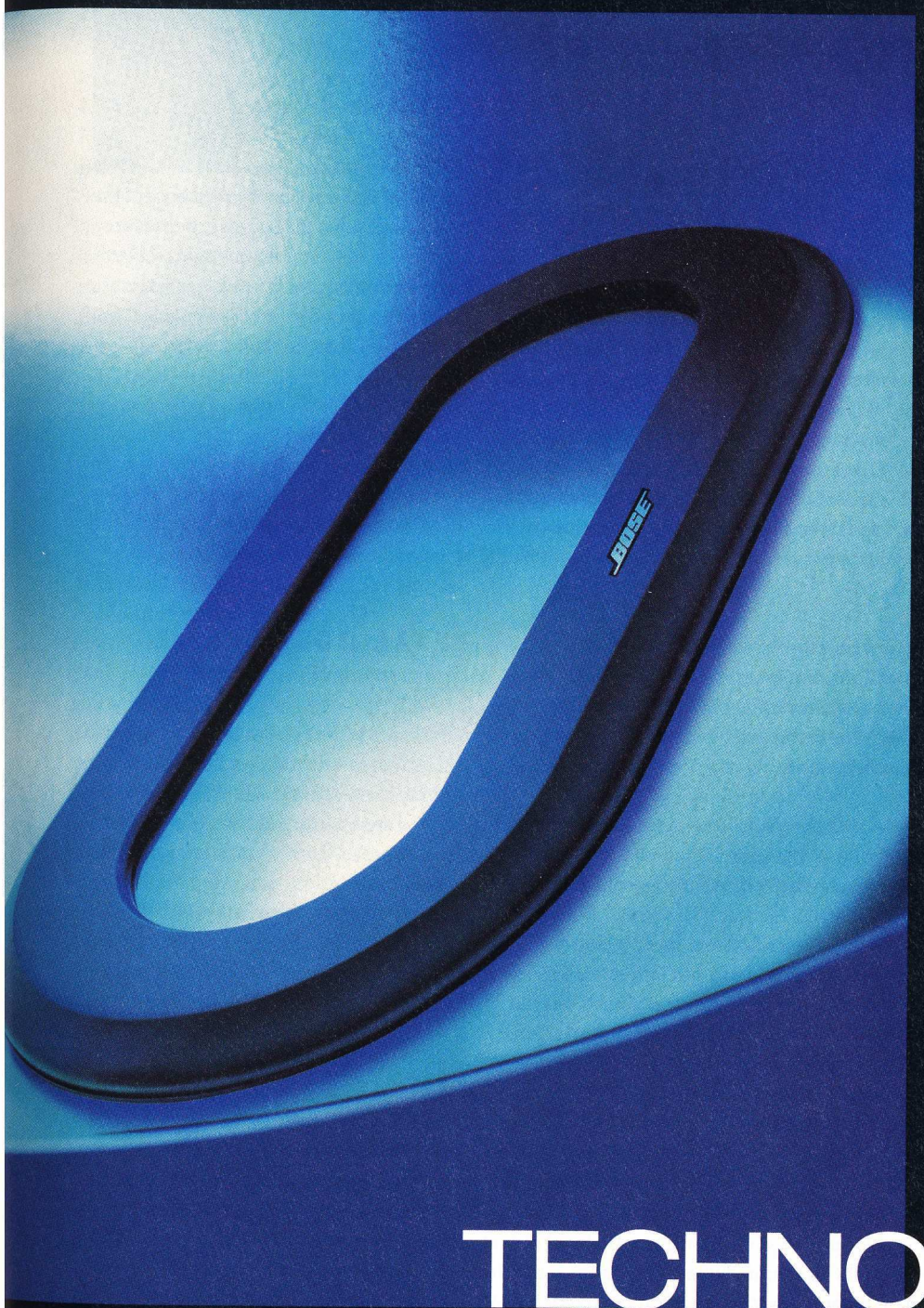

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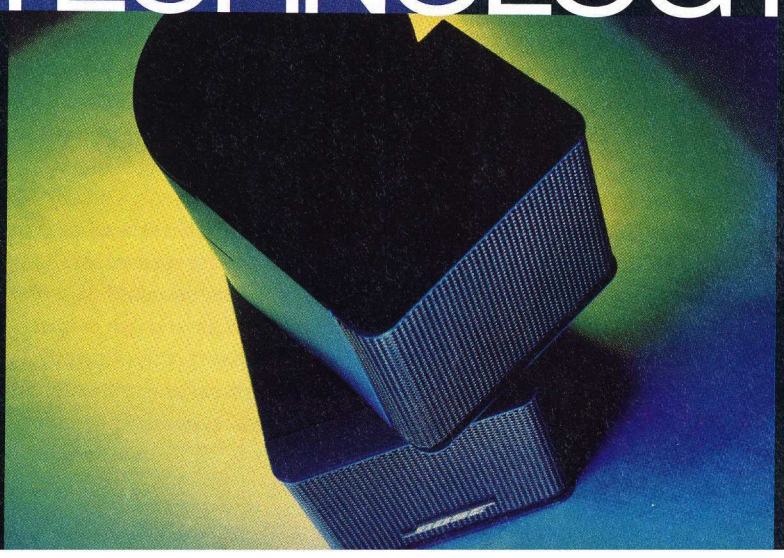


PRODUCTS SHOWN APPROXIMATELY 1/2 SIZE

DAVID SMALL

KRISTI ANSETH, 31
University of Colorado

The ubiquity of plastic in today's consumer culture is annoying, but bioengineer Kristi Anseth wants to see plastic *really* get under your skin. Anseth develops new types of photopolymers, plastics that go from soft to hard when struck by ultraviolet light. Similar materials are used by dentists to plug cavities, but Anseth has invented novel photopolymers that actually wear away over time—a feature that promises much for orthopedic repairs. The idea, says Anseth, "is to have the polymer material degrade predictably and on schedule with the body's own bone healing."

Anseth's polymers are now being tested in mending serious fractures and patching holes left by bone cancer. With precise control over the speed at which the polymers dissolve, Anseth envisions implants that might also release timed doses of bone-healing growth factors.

Tissue engineering is up next. Anseth is working to combine photopolymers with lab-grown cartilage to create a living implant that can mend worn-out joints. It is a more difficult problem than patching bone, according to Anseth, because "cartilage does not have the capacity to heal itself the way bone does." Collaborators at Massachusetts General Hospital in Boston are testing Anseth's technique in animal models. Anseth's ability to wring the most out of materials is evidence of a "superior creative genius" according to Robert Langer, an MIT professor and the father of modern biomaterials.

ADAM ARKIN, 33
Lawrence Berkeley National Laboratory

So far, says a recent *Nature* editorial, molecular biology has produced only a "cartoon representation" of life's myriad molecular pathways. And although "superb papers have been written for the purpose of adding a single arrow to an existing cartoon," *Nature*'s editors concluded that the agenda for the next century is to add numbers to each arrow, and then equations to connect the arrows—only then will we learn to control specific processes when they go awry, as in cancer.

In a study hailed as a "benchmark for all future papers in the area," Adam Arkin created a computer model connecting the arrows of the genetic circuit that controls when a bacteriophage virus decides to begin reproducing. Biologists had advanced several reasonable theories, but Arkin and his Stanford advisor Harley McAdams proved that the virus' decision is in fact determined largely by chance chemical events.

A rising star in Lawrence Berkeley's physical biosciences division, Arkin wants to go way beyond viruses, creating computer simulations that explain how genetic "switches" are thrown during human development to orchestrate the formation of our bodies. To get there, Arkin is developing a generalized modelling program known as Bio/Spice, named after software used by engineers to analyze electrical circuits. Arkin's work foreshadows the biology of the next decades, when researchers begin to understand and control the cell's own circuitry.

TEJAL DESAI, 27
University of Illinois, Chicago

Microelectromechanical systems, or MEMS, are millimeter-scale machines etched from silicon. These Lilliputian devices are opening up whole new frontiers in areas from communications to energy production *(see "May the Microforce Be With You," TR September/October 1999)*. Tejal Desai aims to see MEMS conquer another field: bioengineering. Desai is using micromachining to create tiny implants that can carry needed cells into ailing bodies, all the while protecting them from attacks by the immune system. In one project, she prototyped a biocapsule for diabetics designed to deliver pancreatic cells to boost insulin production.

"She's rapidly becoming one of the most established researchers in the biomedical applications of nanotechnology and bio-MEMS," says Mauro Ferrari, director of Ohio State's Biomedical Engineering Center. At just 26, Desai became the first professor hired into the University of Illinois' newly created department of bioengineering, whose director Richard Magin says, "If I could clone Tejal, I would." Luckily, Desai is already working to clone herself: She's deeply involved with organizations that encourage girls and minorities to study math and science.

JAMES COLLINS, 34 *Boston University*

Without James Collins, stochastic resonance might have ended up science trivia—now it may give a big boost to patients. Stochastic resonance is a paradox in signal detection: Adding noise to a signal can sometimes make it easier to perceive. Collins had the outside-the-box idea that electrical noise could make mechanical signals easier for people to sense. It does: He found that people feel otherwise undetectable pricks in the presence of low-level electrical noise, opening the way to sensory prosthetics for touch-impaired diabetics, stroke patients and the elderly.

BOSTON UNIVERSITY PHOTO SERVICES

What's more, Collins has taken similar approaches down to the biomolecular level, showing how electric fields can cause controlled increases of protein production in laboratory bacteria. According to former BU colleague Charlie Cantor, now chief scientist at Sequenom, a San Diego biotech company, this physics-based approach to biology is totally new. Collins, says Cantor, "is applying nonlinear dynamics principles and methods to build molecular control systems to change the properties of living cells. This kind of work has the potential to revolutionize areas like gene therapy."

SANDRO DE SOUZA, 31

Ludwig Institute for Cancer Research

Genome research is big science—and it costs big bucks, which is why it's centered in the United States, Europe and Japan. But thanks to scientists like Sandro de Souza, developing nations, such as his native Brazil, are not entirely out of the game. De Souza's specialty is bioinformatics: computer-driven gene research that's relatively cheap to get into, and where there's great science to be done. As a postdoc in Nobelist Walter Gilbert's Harvard lab, de Souza helped solve a crucial mystery in the evolutionary history of genes, a breakthrough Gilbert attributes to de Souza's "technical abilities and profoundly creative insights."

Now de Souza is home, where he says he is turning bioinformatics into "an opportunity to do front-edge science" in his native country. He works for the São Paulo arm of the Ludwig Institute for Cancer Research, a global research institution that's partnered with local government to launch a gene discovery project. Heading up the bioinformatics branch, de Souza will play a key role in unearthing genes associated with stomach and breast cancers—tumors especially prevalent in São Paulo, where cancer is the leading cause of death. De Souza will organize the genes into a database accessible to scientists worldwide, including collaborators at the National University of Singapore's Bioinformatics Center, where de Souza is also a faculty member.

L. BARRY HETHERINGTON

DANIEL DILORENZO, 33

University of Utah Medical School

Like many inventors-to-be, Daniel DiLorenzo was fascinated with electricity and moving parts at an early age. By fifth grade, he'd assembled his first electrical circuit. As a high school senior he built a four-legged robot, and by the time he graduated from college he'd designed a digital control system to make the robot walk.

Despite his aptitude for hardware, DiLorenzo always wanted to be a doctor. So he set out to become a physician-inventor, and in June earned both a PhD in mechanical engineering from MIT and an MD in a joint Harvard-MIT program. Innovations like a patented method to control brain swelling during surgery and a project that used muscle-stimulating electrodes to enable a spinal-cord injury patient to walk 20 meters in the lab earned DiLorenzo this year's $30,000 Lemelson-MIT Student Prize for Invention.

DiLorenzo started his residency at the University of Utah Medical School this fall, and is set on becoming an expert in functional neurosurgery. DiLorenzo is likely to play a key role in this emerging discipline, which looks to combine electronic brain implants and nerve stimulation to restore motion to the paralyzed and lost senses to the blind and deaf.

JOHN DOBAK, 34 *Innercool Therapies*

John Dobak is as persistent as frost on a January windowpane. Working in the dermatology clinic during his med school residency, Dobak was trying to freeze a wart off a patient using cryosurgery—the destruction of tissue by the application of extreme cold—when he tipped over the day's supply of liquid nitrogen. After resorting to a simple, plug-in electric scalpel, Dobak started wondering why there weren't any equally cheap and efficient devices for cryosurgery. He never let the question drop.

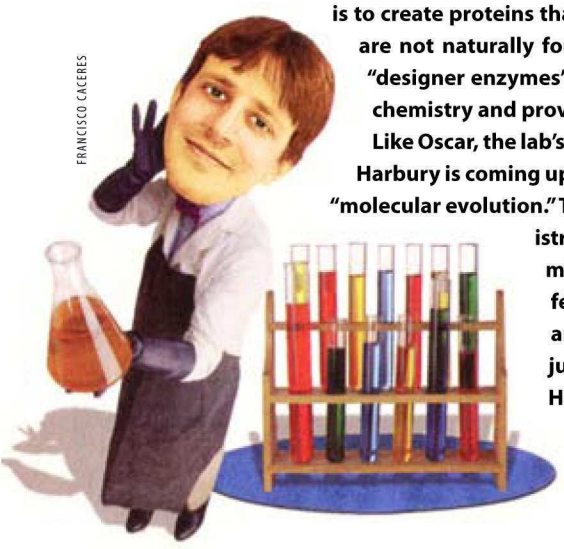
Operating from home, and funded by his VISA card, Dobak designed and patented a "closed-cycle" cryogenic device that wouldn't leak chilled liquids. After hitting a dead-end marketplace in dermatology and initially rebuffed by the technological challenges of cardiac surgery, Dobak eventually launched his first company, Cryogen, to make a new instrument for gynecologic cryotherapy. The simple, compact cryo-device the firm developed has won design awards for its ease of use, and is now being tested for treating excessive menstruation by freezing the cells that line the uterus. The approach may prove safer and cheaper than alternatives such as hysterectomy.

This year Dobak started Innercool Therapies, which is working on a Dobak-designed catheter that slows damage from strokes by chilling blood on its way to the brain. With eight patents issued, and another eight pending, Dobak's inventions have so far garnered a cool $42 million from venture capitalists.

PEHR A. B. HARBURY, 34 *Stanford University*

Rational drug design and combinatorial chemistry are the Felix and Oscar of biochemistry. The first aims to design new compounds from scratch—the other scoops them up after a throw of the chemical dice. But these opposites are no odd couple in Pehr Harbury's hands. Harbury specializes in the finicky, Felix-like business of designing proteins on a computer, modeling them down to the level of individual atomic bonds. The goal is to create proteins that can catalyze chemical reactions that are not naturally found in living organisms. If successful, "designer enzymes" could revolutionize synthetic organic chemistry and provide new tools for drug discovery.

Like Oscar, the lab's second line of research loves a gamble. Harbury is coming up with ways to produce better drugs via "molecular evolution." This variant of the combinatorial chemistry theme is a trial-and-error method that mimics how the body's immune system fends off invading pathogens by mixing and matching molecules until it hits on just the right antibody. According to Harbury, this two-pronged approach is a good bet to adapt life's mechanisms in ways that serve both science and medicine.



FRANCISCO CACERES

PATRICK JENSEN, 33 *Johns Hopkins University*

The eye is one of Nature's great engineering feats—a delicate combination of optics, mechanics and electronics. For biomedical engineer Patrick Jensen, healing sick or blinded eyes is an opportunity to display similar virtuosity.

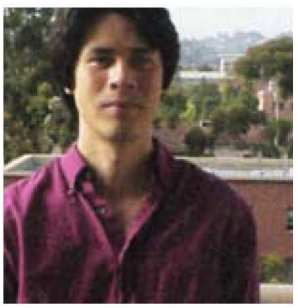
As co-director of the MADLab, the Microsurgery Advanced Design Lab at Johns Hopkins University's Wilmer Eye Institute, Jensen works to join electromechanics, optics and software in order to extend the limits of the surgeon's perception and dexterity. One example: force-feedback robotic systems that speed up operations and make them safer by enabling surgeons to "feel" the fragile retina as they repair it. Jensen's lab is a key player in a 10-year, National Science Foundation-sponsored collaboration with MIT and Carnegie Mellon on computer-enhanced surgery.

Unlike researchers who invent new technology and then go looking for applications, says Matthew Glucksberg, who heads the Northwestern University bioengineering lab where Jensen did graduate studies, "Patrick's real strength as a technologist is that he sees the physiological problem." Jensen also knows what it takes to see new inventions into clinical use; the MADLab works closely with commercial partners and has licensed 30 products.

CHRISTOPHER LEE, 33 *University of California, Los Angeles*

Christopher Lee calls it the "great anticlimax" of the Human Genome Project. "We've generated massive amounts of data. If we could only figure out what it means!"

As a leading designer of bioinformatics software, Lee is doing as much as anyone to help biologists mine the mountains of data for clues to how genes work and their role in disease. Among Lee's creations is GeneMine, a program that scours big Internet databases, compiling and analyzing information to identify the most functionally important of the thousands of human genes. Many of the world's largest drug firms have bought a commercial version of the program, which is sold by Molecular Applications Group in Palo Alto, Calif., a company Lee co-founded in 1993 and one of the most successful players in the growing bioinformatics industry.



Lee's latest effort focuses on "single nucleotide polymorphisms," or SNPs, tiny genetic differences between people. He's trying to zero in on the specific SNPs that account for physical traits and for individuals' differing response to drugs. Hunting SNPs in the 6 billion bits of DNA in the human genome is no trivial task, but Lee's enterprising lab recently built a supercomputer out of 150 400MHz Pentium II chips to speed analysis by an order of magnitude. "We are trying to make the most intense meeting of data and theory possible," says Lee.

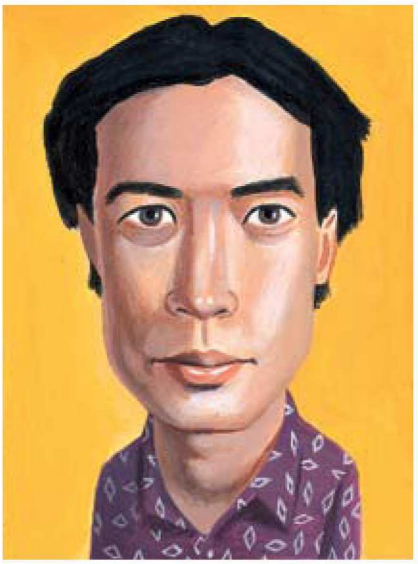
FRANK MONKIEWICZ

SAMIR MITRAGOTRI, 28 *Sontra Medical*

Ouch! And ouch again! As many as five times a day, diabetics endure needle sticks, sampling their blood to ensure their blood sugar remains within healthy limits. Samir Mitragotri envisions a day when measuring glucose levels is bloodless—and ouchless.

The Bombay native invented a way to use low-frequency ultrasound to make skin super-permeable (a process known as sonophoresis), then suck out interstitial fluid with a vacuum. This fluid, which bathes the space between cells, also gives a measure of glucose concentration, and Mitragotri co-founded a company, Sontra Medical of Cambridge, Mass., that's raised $7 million to commercialize the idea. With 16 million diabetics in the United States the need and the market are both considerable.

Sonophoresis can also be used to pump drugs across the skin, but it was only when Mitragotri showed how low-frequency waves make the process 1,000 times more efficient that it became possible to consider transdermal delivery of big protein molecules such as insulin. Combining ultrasound diagnostics and drug delivery, Mitragotri says, could lead to a closed-loop, wristwatch-sized device that automatically monitors and adjusts glucose levels. That would make diabetics' lives not only pain-free, but carefree as well.



CHARLIE POWELL

BRUCE LAHN, 30 *University of Chicago*

Male contraception (i.e., the lack thereof) has been a hot topic in recent years. The research Bruce Lahn does might help bring that elusive commodity closer to reality. Lahn's expertise is human genetics. For his PhD thesis under David Page at the Whitehead Institute, he took on the gargantuan task of cataloging the genes of the human Y chromosome, which distinguishes males from females. In the process he increased the number of known Y genes from 8 to 20. But that achievement was just a warm-up.

As a postdoctoral researcher, Lahn reconstructed a detailed evolutionary history of the Y chromosome and dug into functional studies of the newly found genes. He demonstrated that the Y chromosome carries a wealth of genes implicated in male fertility, a discovery that could open the way for new infertility treatments, perhaps even a male birth control pill that would work by deactivating key genes.

Lahn's undertakings have wowed colleagues, one of whom says that it's his ability to invent clever experimental techniques that lets Lahn singlehandedly generate "as much data as a medium-sized laboratory." Expect Lahn to take on even bigger projects; he's just arrived at the University of Chicago to set up his own lab for the first time.

DAVID MOTT, 34
MedImmune

Credit David Mott with helping send MedImmune to the top tier of today's biotechnology companies. In 1992, Mott left a job as a Wall Street investment banker to oversee business development at MedImmune. But the enterprising Gaithersburg, Md., company hit hard times when a flawed drug study prompted the Food and Drug Administration to nix approval for RespiGam, a first-of-its-kind treatment to prevent respiratory infections in newborns.

Investors drove MedImmune's stock to an all-time low of $2 per share. Then Mott stepped in, assuming responsibility to get the drug back on track. RespiGam won approval in January 1996.

By then Mott had risen to become president and chief operating officer, leading the young company's successful market launch of its first product. Growing sales have driven the firm's stock price over $100.

Merrill Lynch biotech analyst Eric Hecht says, "David is probably the most adept young executive I've ever met, and moves the ball from A to B better and faster and with more energy than anyone." Thanks to driven leaders like Mott, MedImmune's other research programs, including a vaccine against urinary tract infections, stand a better chance of making it to market.

ROBERT A. LISAK

NIKOLA PAVLETICH, 33
Memorial Sloan-Kettering Cancer Center

Cancer is out-of-control growth, caused when a cell's molecular brakes wear out, or its gas pedal gets stuck. Fixing cancer means getting under the hood, and Nikola Pavletich is fast becoming one of the field's pre-eminent grease monkeys.

Pavletich uses X-ray crystallography to map the three-dimensional shape of the molecular components that control cell growth. It's exacting work that's usually done far from the limelight of the latest miracle cure. But Pavletich's depiction of the structure of the tumor-supressing protein p53 in its molecular embrace of DNA landed his work in a Newsweek cover story. The reason? p53 plays a role in half of all cancers, and Pavletich's pictures of the protein in action showed how it can malfunction. The work is a first step toward new drugs that prevent cancers, rather than just killing tumors with devastating side effects to patients. Pavletich's technical skill is matched by a growing reputation for bold science. "Nikola is absolutely fearless in his choice of projects," says Carl Pabo, an MIT biology professor and Pavletich's postdoctoral advisor.

MARK PRAUSNITZ, 33 *Georgia Institute of Technology*

In pharmaceutical companies around the globe, chemists labor for untold hours tweaking newly discovered drugs so that they will enter the bloodstream and reach their targets more effectively. Mark Prausnitz takes a different approach: "I'm choosing to manipulate the body, and have it let the medicine in." As a grad student, Prausnitz showed for the first time how short electric pulses could move large quantities of drugs across the skin, a phenomenon known as electroporation. That approach could help in treating tumors and autoimmune diseases.

Since joining the Georgia Institute of Technology's chemical engineering department, Prausnitz and colleague Mark Allen invented a 10-millimeter-square array of silicon needles (each 150 microns long) that make microscopic holes in the skin and can painlessly pump drugs into the body. The device could offer the convenience of skin patches, but administer a much wider variety of drugs. A startup company, Redeon of Cambridge, Mass., is working to commercialize the invention.

CARMICHAEL ROBERTS, 31 *Surface Logix*

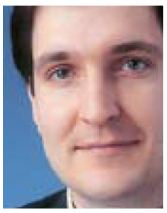
Carmichael Roberts' greatest invention is himself. A scientist with entrepreneurial dreams, colleagues say Roberts has poured unmatched energy into his transition from lab bench to boardroom. After carrying out world-class glycobiology research for his PhD at Duke, Roberts co-founded NPG Research, a nonprofit institute that's landed funds from biotechnology companies and the National Institutes of Health to turn his science into lifesaving drugs. Soon, it was on to an apprenticeship in the for-profit realm when he joined Union Carbide, a chemical firm trying to break into new life-science businesses. After breezing through an eighteen-month training program in four months, Roberts started sizzling up the ranks. But entrepreneurship beckoned, and he headed to Boston where he's getting an MBA from MIT's Sloan School of Business.

FURNALD/GRAY

Roberts didn't wait long before launching his first venture. His startup company, Surface Logix, which he co-founded this year with Harvard nanotechnology guru George Whitesides *(see "Nanotech: Art of the Possible," TR November/December 1998)*, is looking to commercialize a chemical approach to microfabrication. Handing over the promising technology to Roberts doesn't worry Whitesides, who says, "Every one of Carmichael's instincts is what I expect from an entrepreneur with 15 years more experience." Beyond his scientific and business skills, Whitesides says it is Roberts' outstanding human qualities—enthusiasm, humor, courage and caring—that guarantee his success organizing and motivating others to move innovations into the marketplace.

PETER SEEBERGER, 32 *MIT*

Everybody knows that, in fashion, it's accessories that really make the outfit work. Sometimes that's true in biochemistry, too. For instance: a protein's functionality often hinges on the addition of a carbohydrate molecule. Consisting of chains of oxygen, hydrogen and carbon atoms, carbohydrates play a key role in everything from healing wounds to heart disease. Yet their chemistry remains somewhat mysterious, partly because they're tough to make in the lab. Biochemist Peter Seeberger has set out to change all that.



A transplant from Nuremberg, Germany, Seeberger has already dreamed up new ways to string carbohydrates together from their simple sugar building blocks, and also spearheaded the assembly of the most complex carbohydrate ever made by man. Seeberger's work, says University of Colorado chemist Marvin Caruthers, sets the stage for an automated carbohydrate-making device that could "profoundly influence biochemistry and medicine." In Seeberger's lab newly synthesized carbohydrates are already being exploited to probe how cells transmit signals, as well as how immune-system cells recognize HIV and parasites. Those insights could lead to new ways of targeting gene therapies against pathogens, and potent new cancer vaccines. Whether those specifics materialize or not, expect Seeberger to be a leader in discovering how those tricky cellular outfits really go together.

MATTHEW SHAIR, 31
Harvard University


DAVID SMALL

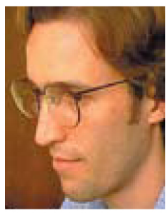
Matthew Shair makes and studies complex molecules at an extraordinary rate. His research is an engine driving important discoveries at Harvard's new Institute for Chemistry and Cell Biology (ICCB), an interdisciplinary collaboration that teams chemists, biologists and medical school faculty with industry researchers. Shair's molecule-making technique is called split-pool organic synthesis, an iterative process that requires highly skilled chemistry and yields vast numbers of distinct, manmade compounds that are as complex as anything found in nature.

Shair's talent surfaced early. As a postdoc in the lab of ICCB director Stuart Schreiber, he spearheaded a project that generated more than two million compounds. Those molecules are a critical enabler of "chemical genetics," a new paradigm for rapidly analyzing the functions of newly isolated genes. "Matthew is on his way to establishing a breakaway research program," says Schreiber. Merck and other corporations contribute heavily to ICCB to see early results from this work. Their bets are not misplaced.

JASON SHEAR, 32 *University of Texas*

One of the driving concepts in biology these days is an idea insiders call "The Movie": a depiction of a cell in which the action of all life's molecules—genes, enzymes, nutrients and the like—can be seen in vivid detail, close up, and in real time.

The movie doesn't exist yet, but talented technologists including Jason Shear are working hard to bring it into focus. Combining a grab bag of advanced imaging technology and analytical methods, Shear is developing a system to record chemical communiqués between neurons as they happen—for instance measuring the neurotransmitter serotonin as it's secreted across a living nerve cell junction, or synapse. The design will use robotically controlled silica needles, nanometers in diameter, to sample the chemicals present inside lab-grown neurons, then measure them with an ultrasensitive detection method called multiphoton excited fluorescence.



If Shear's approach works, it will produce scenarios guaranteed to keep neurobiologists riveted. Shear hopes the denouement will be a better understanding of the chemical basis of learning. This work-in-progress isn't Shear's first clever invention; another scheme used nerve cells themselves as molecular detectors, and with colleague Eric Anslyn he's developed a chemical-sensing "Electronic Tongue."

DARI SHALON, 34
Harvard University

The microscope. The X-ray machine. PCR. Every once in a while, a technology comes along that transforms the way biologists see the world. The latest in this lineage is the DNA chip: a combination of chemistry, imaging equipment and genetics that allows scientists to peer into a cell and measure the activity of its genes, tens of thousands at a time.

Within a few years of their debut, DNA chips have transformed genome research and sped up the search for new drugs. This process wouldn't have happened as fast without the work of technologist/entrepreneurs such as Dari Shalon. In 1992, as a Stanford PhD student, Shalon co-invented a type of DNA chip—and immediately saw its commercial potential. Shalon beat competitors to the punch with a clever business plan in which his startup firm, named Synteni, did experiments on the cheap for customers rather than selling them big costly systems. The rest is history. Synteni was a smash hit, and was soon bought out by Palo Alto, Calif., gene giant Incyte Pharmaceuticals.

Recently, Shalon's mix of scientific, technological and business acumen landed him the director's post at Harvard's Center for Genomics Research, a new multimillion-dollar hub for multidisciplinary life sciences research. Shalon says he's working to build "a strong intellectual community [that] integrates research in biology, chemistry, physics, engineering and medicine." This eclectic enterprise, Shalon predicts, will be "a powerhouse" in inventing eye-opening new genomics technologies.

Big Technology

The Internet has given rise to huge collaborations spanning disciplines and national boundaries

TR100

COLLABORATION THEME

If you needed to pick one word to describe the modus operandi of the TR100, it would be "collaboration." Thanks to databases and the Internet, the ability to share immense amounts of data has grown rapidly. The result has been the formation of "virtual" communities involving hundreds—even thousands—of researchers in areas as diverse as software, genomics and materials science. Although large-scale cooperation in technology isn't new, these cutting-edge collaborations bring with them new features: "bottom-up" rather than "top-down" management, the involvement of a broad geographical mix that includes participants from developing countries, and the possibility of cooperation between companies that are fiercely competitive.

In the past, most large technological collaborations were directed from the top. But the "open-source" software movement challenges that style of project management. The open-source movement has been around for a while, but it got a jolt of new energy in 1991, when a Finnish student named Linus Torvalds wrote the "kernel," or core, of a new operating system based on Unix and posted it on the Internet. Torvalds encouraged others to improve and expand his system, which came to be called Linux. Thanks to the Internet, programmers could discuss their needs, develop and submit code changes and obtain the latest version of the code instantaneously.

Linux is not the only important open-source project going on now. Apache, cofounded by the TR100's Roy Fielding, is Web-server software used by more than half of all public sites. GNOME has put a friendly user interface on Linux. These projects are not led from above but "coordinated"—Apache by Fielding and GNOME by the TR100's Miguel de Icaza. Any participant can drive the direction of software development, if he has a compelling argument and produces the code to go with it. The coordinator's role, says de Icaza, is not to dictate direction but simply to "make sure people aren't duplicating work, and get them to work together."

The networking technology that makes it possible for large groups to work together without much hierarchy can also facilitate cooperation across national and even language barriers. Take genomics, where the ability of computers and networks to store vast amounts of genetic data and make it readily accessible means scientists around the world can work on a common dataset. As a result, says the TR100's Sandro de Souza, genomics has become a global research enterprise; even scientists in developing countries with limited access to funding and high-priced instruments can do cutting-edge research. Working in his native Brazil, de Souza is helping to coordinate genomics efforts in that country. "We set up a network of about 30 laboratories," says de Souza. "Some build the DNA libraries, others do the sequencing, and a few others do the analysis."

The Linux brigade and genomics projects operate primarily in the academic and public sectors. But collaboration also looks like the wave of the future for many high-tech companies. The high price of certain types of research—work on next-generation chip fabrication, say—is pushing erstwhile competitors into a cooperative posture. Motorola, Intel and Advanced Micro Devices, for example, are working together on chip fabrication methods. The TR100's Christine Smith, who helps foster collaborations, says getting the project running wasn't easy: "It took a neutral party—the Lawrence Livermore National Laboratory—to bring it all together." Smith points out that one of the complexities in bringing different organizations into collaboration mode is sorting out intellectual property rights for any discoveries.

In spite of such complexities, the experience of the TR100 suggests that collaborations, on a grand scale, in intriguing new forms, will bring forward many future breakthroughs.

—Nick Montfort

ERIK WINFREE, 30
Princeton University

Computer scientist Erik Winfree embodies the remarkable potential of the spot where biology and engineering meet. For his PhD project, Winfree zeroed in on the natural inclination of corresponding strands of DNA to zip themselves up into a double helix. Could such "self-assembly" reactions be harnessed to carry out basic computational processes? In work that extended existing theories of DNA-based computers, Winfree showed that the reactions should be able to carry out all the operations of a computer, doing anything from crunching prime numbers to playing chess.

In Winfree's world of biological computers, both the information "input" and the "output" come in the form of molecules. As a result, the same methods can be used to assemble nanostructures. Imagine simple DNA elements prepared ("programmed," if you will) to automatically assemble into a complex structure, like a jigsaw puzzle solving itself via chemical reactions. With New York University's Ned Seeman, Winfree designed a self-assembly reaction to construct a two-dimensional DNA crystal. Winfree sees no reason to stop there. The DNA self-assembly approach could eventually lead to new ways of building more complex materials—even nanometer-sized electronic components—one molecule at a time.

David Baltimore, president of Caltech, where Winfree will join the faculty in 2000, calls Winfree "an unconventional thinker" whose work "will open up entire new areas of inquiry."

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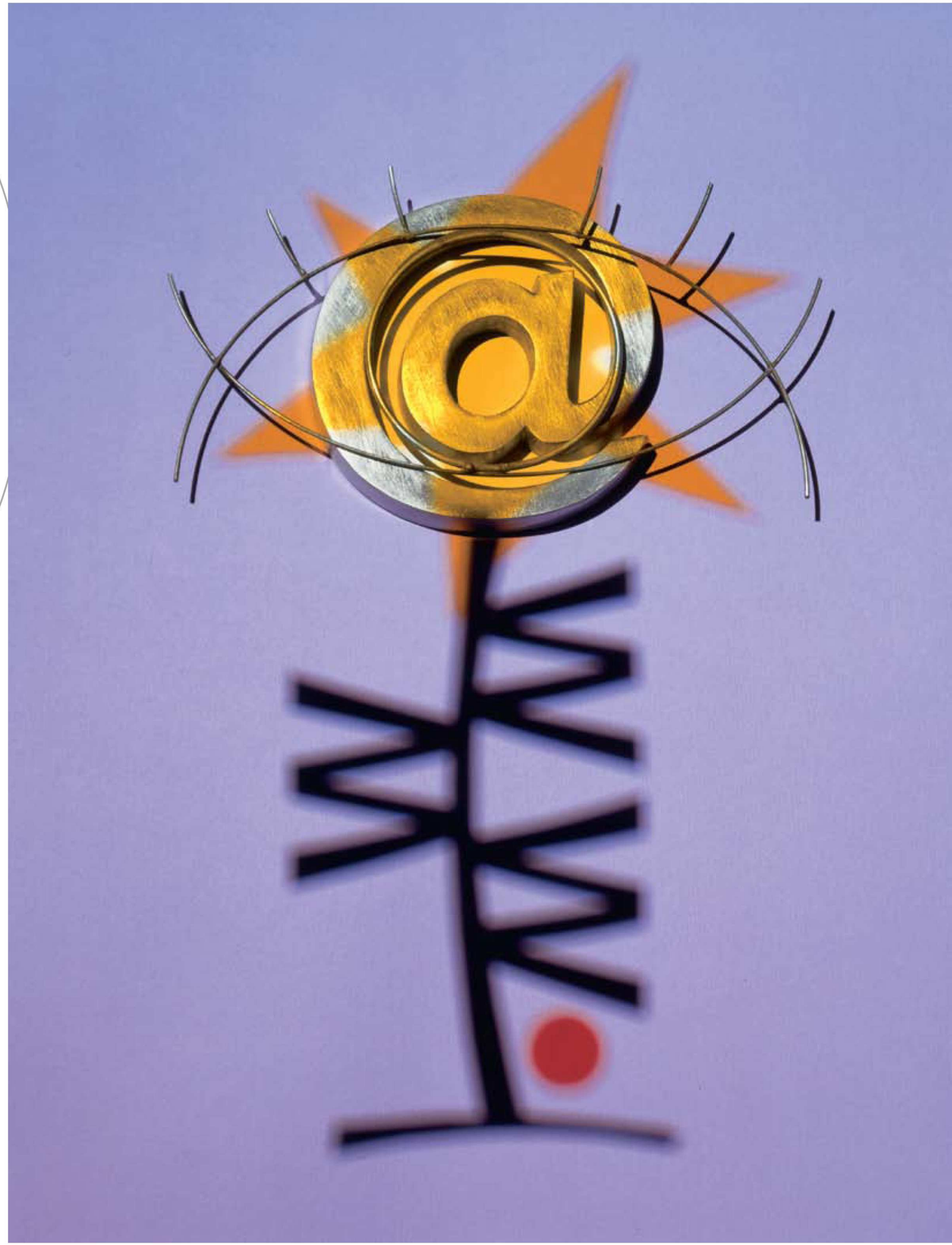
World Wide Web

WHERE TELECOMMUNICATIONS AND THE WORLD WIDE WEB ARE concerned, the last decade has been nothing short of amazing. Could the next decade possibly be as dramatic as the last, in which the PC became widespread and the Internet global? Yes, indeed, say the TR100, led by **Shivkumar Kalyanaraman**, who cites Metcalfe's Law to bolster his view. Metcalfe's Law, formulated by Ethernet inventor and 3Com founder Bob Metcalfe *(see "Invention Is a Flower, Innovation Is a Weed," p. 54)* holds that "the value of a network like the Internet is at least of the order of N^2, where N is the number of users of the network," says Kalyanaraman. With the growth of human access and the explosion of small networked devices, which are themselves network "users," that N will grow exponentially over the next decade. Square that massive number, and you begin to appreciate the value and impact of the Internet at the end of the next 10 years. According to Kalyanaraman, "the effect seen by the world will be much, much more profound than the revolution brought about by PCs."

We questioned some leading lights among the TR100 to learn about that global effect. Although their views varied, some themes surfaced again and again: Internet access will be pervasive; it will take different forms than the ones we know now; most commerce will soon be e-commerce; and a variety of social and political dangers will come along with the benefits from these changes.



But I Diverge...

WHEN IT COMES TO MEDIA THESE DAYS, A LOT OF PEOPLE ARE talking about "convergence," a discussion that's driven largely by the fragmented and inconvenient way we absorb information and entertainment. Says TR100 member **Peter Girardi**, a multimedia artist and founder of a company called Funny Garbage: "If in ten years I still have to sit at a computer in a different room in my house than the TV, using a 'browser' over a crippled telephone line, squinting to see ten-point aliased type, making folders on my faux 'desktop,' and cleaning the goo out of my 'mouse,' something will be very, very wrong." Some members of the TR100 argued that, in response to this inconvenience, the TV and PC may converge—yielding a single, easy-to-use entertainment/information center in the home.

But that wasn't necessarily the consensus view. Most of the TR100 were more interested in what might be called media *divergence*. Indeed, on this subject, they were nearly unanimous: In the next decade there will be a wild blossoming of network devices that go way beyond today's handhelds and PDAs. The Internet, they say, will reach a massive array of networked devices, large and small, which bear no resemblance to the traditional beige box or the television set. This trend goes by many names. It is sometimes called "pervasive computing," but it's also known by other terms: ubiquitous computing, lifestyle computing, Web appliances, and Internet appliances.

Kalyanaraman spoke for many when he said: "Computers will become smaller and smaller, and any device running on electricity can become connected. With the advance of wireless and satellite technologies, these devices can be with you anywhere on the earth." **Natalie Jeremijenko**, who worked at Xerox PARC in the Ubiquitous Computing group, sees networked computing becoming pervasive, but perhaps not reaching everywhere electricity does. "Not everything needs to be networked all the time," she says, giving the example of a digital version of today's yellow highlighter that can store data about a user's study habits, helping the user understand his or her own patterns of absorbing information when the device is later docked with a PC.

BigCo Is Watching You

THE TR100 WERE GENERALLY ENTHUSIASTIC ABOUT THE BENefits of pervasive networked computing power. But they also pointed out that ubiquitous networking means information is flowing in many directions—not all of them equally desirable. Although such issues have not been a big part of the American policy debate, "the public debate in Europe…has focused on protecting the individual against data abuse by organizations," says Web standards developer **Håkon Wium Lie** of Opera Software. "I find these laws more important for my own privacy than access to strong cryptography."

Personal access to powerful methods of cryptography has been advanced by some civil libertarians as a critical tool for preserving individual privacy, but Lie and others argue that it's more important to keep an eye on how corporations deal with personal data. "An overarching surveillance state isn't as likely as the dangers of private surveillance," says **Andrew Shapiro**, who heads the Aspen Institute's Internet Policy Project. While Congress has been active in passing laws that corporations favor, Shapiro notes that there have been almost no new laws to protect individual privacy in recent years. **Jonathan Nelson** of Organic Online thinks the biggest threat won't come from e-commerce firms. He says he is more concerned about entities such as credit reporting agencies, which collect reams of data but aren't accountable to any of the people they keep files on.

One effect of growing e-commerce is "an unprecedented opportunity for violation of our privacy," agrees Georgia Tech's **Amy Bruckman**. But Bruckman believes that Internet data and privacy are moving from the realm of specialist concerns into much broader consciousness. "Over the last year or so," she says, "there has been an explosion of public awareness in this field." Cryptography restrictions as well as corporate data collection are now being recognized as subjects worthy of political debate. Awareness alone will not solve these problems, but Bruckman sees it as the first step toward future solutions.

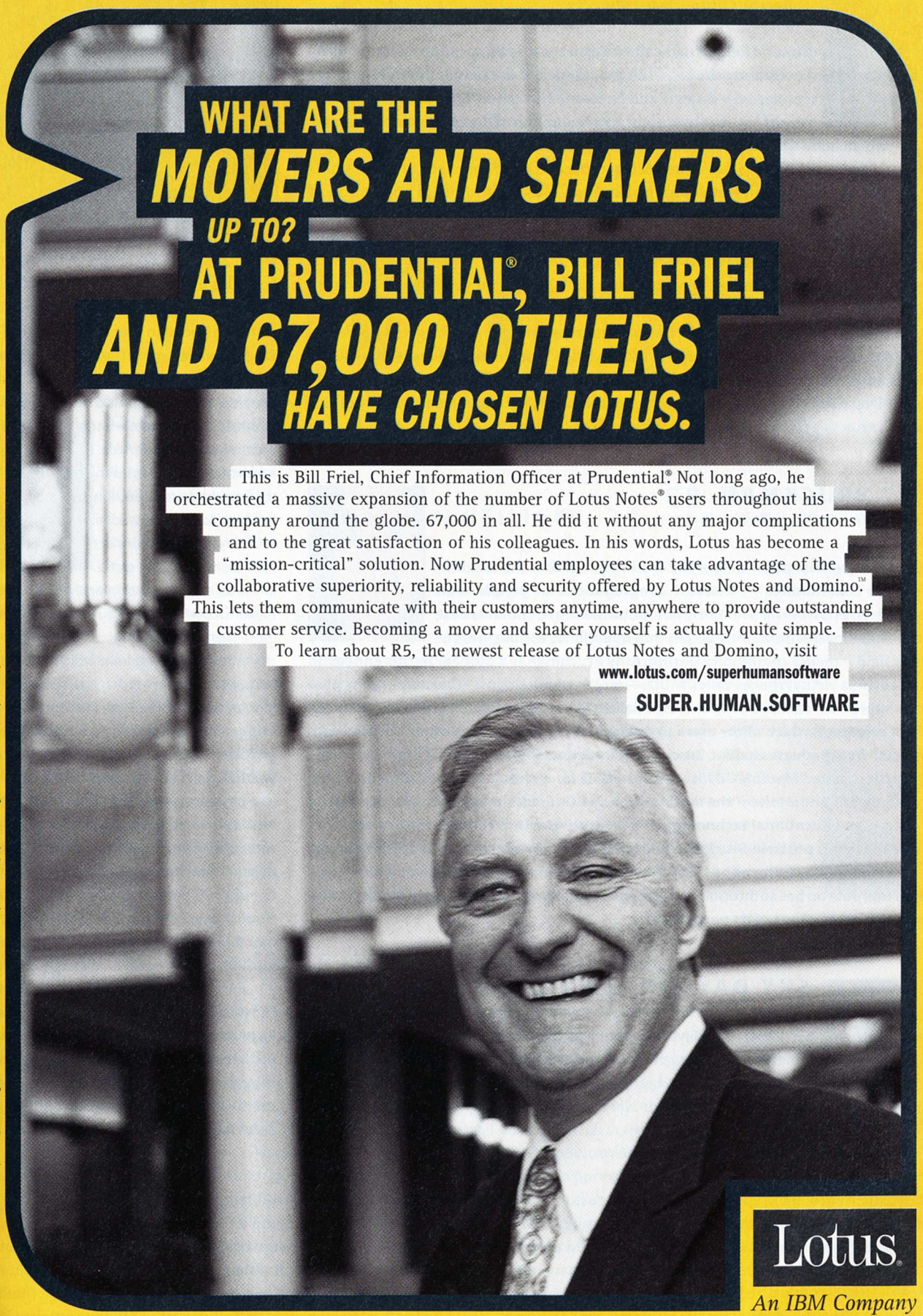
Two Sides of the E-Coin

WHAT WILL PEOPLE BE DOING WITH THEIR NEW, UBIQUITOUS access to the Internet? Buying, of course. Many of the TR100 say that within the next decade e-commerce will become the main way people in the United States buy and sell. Prices could drop and selection increase, as we often hear. But the TR100 also pointed to less well-publicized aspects of e-commerce: Local communities may have to deal with a massive loss of retail jobs and a disruption of their social and economic structure.

The Aspen Institute's Shapiro said he foresees "a real displacement of commerce from local communities to Amazon and the like," manifesting itself, in part, in a $12 billion shortfall in sales taxes next year. Pervasive Web access may not only disrupt local economies; it could also worsen the plight of those without access. This can happen in ways that are not immediately obvious, say some of the TR100. If classified advertising moves online, for example, job-seekers who are not connected will not be able to look for work in the classifieds. Shapiro suggests that a lot of people who now work in traditional retail stores could be in this category soon.

The troublesome effects of e-commerce won't be evenly distributed, the TR100 say. **Michael Robertson** of MP3.com thinks that, for goods such as recorded music, the Web could actually provide ways to circumvent the retail giants—opening a direct link between artist and audience.

On the global scale, the economic aspects of ubiquitous networking are also ambiguous. Some experts have argued that the Web could exacerbate the fissure separating haves from have-nots. But here the TR100 seemed upbeat, pointing out that the digital world could be a boon to developing countries—if they can get access. "Access to the Internet is even more important in the emerging market countries as a way to bridge the gap that exists between the developing world and the developed world," says **Côme Laguë**, who deployed a system of pay phones, Internet kiosks and pagers in Africa. "By obtaining access to the Internet, customers in these markets have access to vast amounts of information and a global market for their goods and services." But as Laguë's work—which involved tight budgets and ingenious stopgaps—shows, bringing access to the developing world is a challenge. A challenge the TR100 are helping to meet. TR



MARC ANDREESSEN, 28

America Online/Netscape

First he helped make the Internet accessible to nonprofessionals by co-creating the browsers that launched the public's stampede to get connected—Mosaic and Netscape Navigator. Then at 23, he became one of the first overnight Internet multimillionaires when Netscape, which he co-founded, made its Wall Street debut. When America Online bought Netscape in 1998, Marc Andreessen became CTO. In September, after 7 months guiding a company with as many subscribers as the combined population of Denmark and Sweden, he stepped aside. The move leaves him connected to AOL as a part-time consultant. Fittingly, this super-entrepreneur will advise the company on its investments in high-tech startups.

At 6 feet 4 inches, Andreessen exudes gawky charm, and displays a polymath's knowledge of the most exotic subjects. An Internet analyst told *Fortune:* "When Marc doesn't know about something he thinks he needs to understand, he gets a book and talks to people and learns. The guy has a knowledge base that is just incredible." Ultimately, his greatest influence on the future of technology could be the outcome of the Justice Department's antitrust suit against Microsoft, in large part the result of Bill Gates' business practices vis-à-vis Andreessen's Netscape.

AMY BRUCKMAN, 33

Georgia Institute of Technology

STANLEY LEARY

One of the greatest potentials of the World Wide Web is the creation of online communities—electronic congregations of people with shared interests from all over the globe. But which environments best foster these interactions? Answering that question is the business of a new field—online community design. Amy Bruckman is a pioneer in this endeavor. She develops virtual spaces called MUDs—multi-user domains—that allow many people to interact in real time. Bruckman specializes in a subset of MUDs called MOOs (MUD, object oriented), which allow users to interact not only with each other but also with "objects." As a graduate student, Bruckman founded an online community for new-media researchers called MediaMOO, as well as a MOO for children called MOOSE Crossing. Bruckman has undertaken "the most notable MOO research in education," says Aaron Tornberg, an educational technology researcher at the University of Cincinnati.

To make this possible, Bruckman had to design a new interface, as well as a new programming language. Once she creates virtual communities, Bruckman doffs her engineer's cap, puts on her anthropologist hat, and studies how the online environment influences the interactions of its participants.

SKY DAYTON, 32 *Earthlink Network*

In 1994, Sky Dayton wanted to connect to the Internet, just then emerging as a nugget of ground truth from the fog of hype about an "information superhighway." Dayton toiled nearly 80 hours configuring his computer for Net access—a numbingly complicated chore. Intent on simplifying this task, he founded Earthlink Network—now one of the nation's top five Internet service providers (ISPs), with more than 1.3 million subscribers. Attribute that success to Dayton's near-religious commitment to the user's experience: from spending heavily on customer service to innovations such as introducing the $19.95 monthly flat rate for unlimited surfing. That change came in November 1995, when most ISPs were still clinging to the notion of hourly fees.

Dayton—a high-school graduate who started up a West Hollywood, Calif., coffeehouse before getting into the Internet business—believes the Internet is the next great mass medium, replacing television. While that's no mental stretch, getting the masses connected is: Only one in five Americans now has Internet access. Earthlink is working to connect the rest, and Dayton remains chairman of the Pasadena, Calif.-based company. Meanwhile, he is looking to play a new role in the Internet's growth through eCompanies, a Santa Monica, Calif., incubator for Web startups that he launched over the summer with executives from Disney.

JAMES PATRICK DAWSON

SABEER BHATIA, 30

Arzoo

Sabeer Bhatia arrived in the United States from Bangalore at 19; now he's a Web gazillionaire. With friend and co-worker Jack Smith, Bhatia founded Hotmail, the first free Web-based e-mail service. This concept was a radical departure from the dial-up services that required a paid account. Hotmail, in contrast, could be accessed via a Web browser from any computer connected to the Net. The idea found a market niche. Make that a cavern: After two and a half years, Hotmail had 25 million active e-mail accounts; now there are more than 50 million.

After emigrating from India, Bhatia studied at Caltech as an undergrad. While attending graduate school at Stanford, he was inspired by high-tech successes like Steve Jobs and Scott McNealy. In August 1995, Bhatia and Smith began seeking capital for "JavaSoft," a Net-based personal database. The reception was lukewarm, but at the same time they were shopping Hotmail, which proved to be a more dynamic prospect. Venture capital firm Draper Fisher Jurvetson invested $300,000, and Hotmail launched on July 4, 1996. Just 18 months later, Microsoft bought the company for $400 million worth of Microsoft stock.

For the passionate innovator, a success like that is just a prelude. Bhatia is now president and CEO of Arzoo, an e-commerce startup that intends to offer a set of integrated e-commerce tools, such as a "shopping cart" that users will be able to push down the digital aisles from site to site.

ROY THOMAS FIELDING, 34

University of California, Irvine

Without public streets, common laws and mutually held beliefs, life would be nasty, brutish and short. So would a trip on the Web if it weren't for Roy Fielding.

Fielding is a primary force behind open-source software, a movement that has brought transparent standards to the most widely used Internet programs. Fielding's first big contribution came in 1994, when he invented a way for browsers to efficiently update stored Web pages, by transmitting information only if something has changed. Without this traffic-saving advance, the Web might have collapsed under its own explosive growth. Thanks to that success, Fielding was tapped by WWW inventor Tim Berners-Lee to author the latest version of the Hypertext Transfer Protocol (HTTP), the standard that governs how computers exchange text, image, video and sound over the Internet.

Fielding's dedication to open standards means that no single company can control the Web. Indeed, Fielding, who is due to receive his PhD this year from the University of California, Irvine, is also cofounder and chairman of the Apache Group, a collective of programmers whose free software now powers more than half of all Web servers—trouncing competition from Microsoft and Netscape.

PETER GIRARDI, 33 *Funny Garbage*

Peter Girardi calls what he does "translation." What he means is that he's moving words written in traditional media—cartoons, theater and music, for example—into the digital realm. Girardi is well placed to do this work, because the transition from conventional media to bits is one he has made himself. At 16, Girardi was spray-painting New York subway cars. In 1987 he moved from graffiti artist to student at the School of Visual Arts, where he began exploring what computers can do. At Funny Garbage, the company he founded in 1995, he is helping bring interactive technology to many established art forms.

For instance, in his earlier work as creative director of CD-ROM developer Voyager, Girardi produced an interactive CD version of Art Spiegelman's dark "Maus"—the Pulitzer Prize-winning cartoon epic Spiegelman based on his father's experience of the Holocaust. In addition to participating in digital artistic collaborations, his company also does Web site design. Clients range from the popular search engine Alta Vista, for which Funny Garbage created a new interface, to David Byrne's world music label, Luaka Bop. According to Spiegelman, "Peter is the best of the new gardeners landscaping our new virtual jungle."

JONATHAN HEILIGER, 23 *Frontier Global Center*

Even among the TR100, venture capitalist Jonathan Heiliger is a youngster. He got a head start in high technology, working at the Stanford Linear Accelerator when he was 15. From there, he made warp-speed transitions from basic science to network engineering to deal-making. Highlights include designing the network architecture used by megaprovider UUNet and brokering the acquisition of Internet Systems by Frontier Global Center. As Frontier's CTO, he laid out the firm's Internet strategy, formulating a system of data centers connected by high-speed links; Frontier's network hosts 40 percent of the top 100 Web sites.

Being CTO wasn't enough; Heiliger wanted to try being a venture capitalist. For most people that would entail getting an MBA. But Heiliger, who doesn't have a college degree, choose a different track. He drafted a proposal, asking Frontier to start a $30 million venture capital fund and to appoint him to manage it. The company agreed, "rounding" the fund up to $100 million. As *Interactive Week* said, "Heiliger's contribution to the Web's emergence as a medium for reaching the masses is staggering. "Heiliger now says he'd like to be a CEO—if he can find the right small company.

DAVID SMALL

KATHERINE ISBISTER, 30 *NTT Open Laboratory*

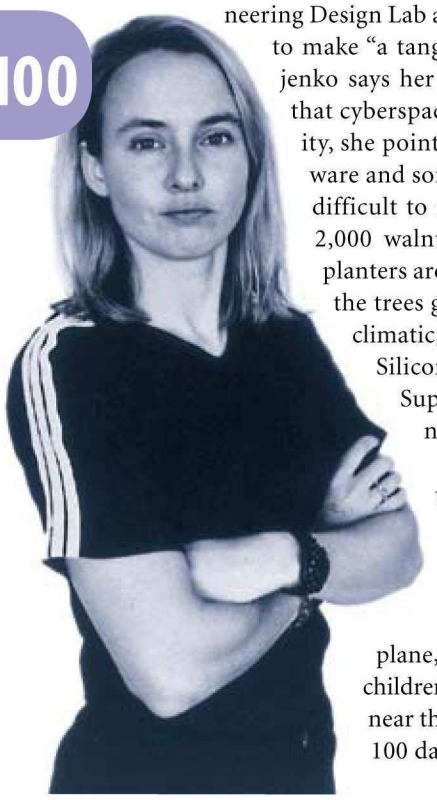
Two hot areas of software design today are intelligent agents to find information and conduct transactions, and realistic depiction of characters (as in movies and video games). What happens when these two pursuits intersect? We get intelligent agents that we can interact with just as we do with people. Having such animated agents may change the way we access the Web and carry on dialogues with people in other cultures. One of the folks hatching such virtual conversationalists is Katherine Isbister.

Animated agents are a natural for communication across cultural barriers, since the agents could store large amounts of information to help the participants understand each other—literally, in language, and also more subtly in culture. Isbister is in the midst of such a collaboration, working at NTT Open Laboratory in Japan. Using a high-speed link between Kyoto and Stanford, she has two students converse across the Pacific, aided by computer characters. Isbister does not just create innovative new interfaces. She also uses social-science methods to study them and draw conclusions about how to improve them. As the world of Web interface design "moves from seat-of-the-pants theorizing to demanding rigorous guidance, Katherine will be a leader," says Clifford Nass of Stanford, who supervised her dissertation there.

NATALIE JEREMIJENKO, 32

"Bureau of Inverse Technology"

Are you a knowledge worker? If so, Natalie Jeremijenko would like you to install *Stump* on your computer. Every time you print out a tree's worth of paper, *Stump* prints a picture of a tree ring. With enough rings, you can reconstruct the stump of a tree.



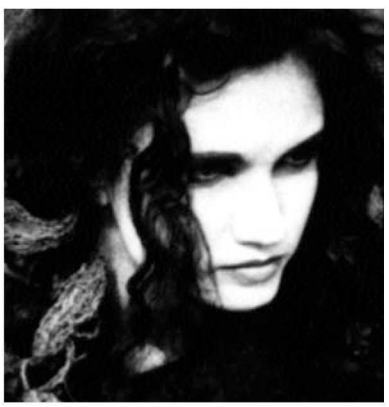
For Australian-born Jeremijenko, who is director of the Yale University Engineering Design Lab and an acclaimed technoartist, *Stump* is a way to make "a tangible version of the Internet world." Jeremijenko says her aim is to pierce the shared "hallucination" that cyberspace is somehow clean and immaterial. In reality, she points out, the digital domain is a world of hardware and some hard truths. Jeremijenko makes the latter difficult to ignore with projects like OneTree, in which 2,000 walnut trees will be placed in sensor-equipped planters around the San Francisco Bay area next year. As the trees grow, their condition will record the region's climatic, socioeconomic and environmental extremes. Silicon Valley is home to a large concentration of Superfund toxic waste sites, and one of the nation's largest gaps between rich and poor.

Jeremijenko, who produces much of her art under the auspices of a fictional institution she calls the Bureau of Inverse Technology, makes novel use of technologies to record social phenomena. She shot a documentary of Silicon Valley from a remote-controlled spy plane, concealed cameras in teddy bears to record children's expressions, and installed a motion detector near the Golden Gate Bridge to count suicides (17 in 100 days).

MAJA KUZMANOVIC, 26

National Research Institute for Mathematics and Computer Science

Digital artist Maja Kuzmanovic has created striking interactive works that bridge different artistic traditions and present the viewer with stunningly different visual worlds. She is now working on the Chameleon Project as artist in residence at the National Research Institute for Mathematics and Computer Science in the Netherlands. One part of the project involves an interaction with what looks like a film clip, using little bandwidth with the recently developed Web tool called synchronized multimedia integration language (SMIL, pronounced "smile").



In 1997 she developed an interactive piece called Once Upon a Moment, about a worker in a dystopian office who is plagued by ever more sinister nightmares. To tell this story, she drew on film, photography and existing new media work to create an interactive movie and Web site. The Croatian-born Kuzmanovic studied art and design in Italy before starting her undergraduate studies at Utrecht University in the Netherlands. There she designed Creation of Change, a CD-ROM that is a collaboration between the disciplines of fashion design, interactive design and graphic design. Interactive art has thus far been a field of enormous promise and uncertain execution. Kuzmanovic might be one of the people who can clarify this murky picture.

CHARLIE POWELL

SHIVKUMAR KALYANARAMAN, 28

Rensselaer Polytechnic Institute

At the dawn of the Internet, back when it was ARPAnet, the task of managing network traffic was pure engineering. But as the Net has exploded in size and economic importance, traffic control has come to depend on other disciplines, such as economics, graphic design, network theory and sociology. The innovators who can bring together people from these and other fields will play a big part in ensuring that the Web grows smoothly. There aren't many people with a high degree of technical expertise and also such a wide-ranging perspective; one of them is Shivkumar Kalyanaraman, professor of electrical, computer and systems engineering at RPI.

Kalyanaraman has made important contributions to research on asynchronous transfer mode, a protocol that permits high-speed network communications. But he joins the TR100 because of the breadth of his vision: In addition to traffic management and congestion control, he also studies Internet pricing, the development of online simulations for network management, and networking for multimedia. He works with network theorists, economists and programmers to study how the Net functions in real time. DARPA, the National Science Foundation and Internet companies are funding his productive collaborations to the tune of more than $2 million—an investment that will pay off handsomely if Kalyanaraman's efforts help stave off a major Internet meltdown in the next few years.

CÔME LAGUË, 33
Adesemi Communications

Many experts fear the Internet will exacerbate, rather than alleviate, the already ominous gap between rich and poor countries. One techno-Samaritan who is giving developing countries a chance to participate in the information revolution is Côme Laguë, co-founder and chief operating officer of Adesemi Communications. Laguë's company has begun expanding telecom services in Tanzania and Ghana and is coordinating the launch of wireless telecommunications services in Sri Lanka, Zambia and the Ivory Coast.

To bring telecommunications to poor countries in Africa, Laguë often must integrate several generations of technology, work around gaps in infrastructure and reduce budgets. Take the Tanzania project, which operated in areas where as few as one in 2,000 people have a telephone. First, Laguë developed a system in which each subscriber has a pager and a voice-mail account—when they get a message, they go to a pay phone. Only problem? No pay phones. So Laguë put in a system of wireless pay phones. Now, even though there may be only one phone in a remote village, any villager has access to phone service. That kind of ingenuity on behalf of poor countries makes Côme Laguë a champion whose work deserves emulation.


SUSAN LAPIDES

HÅKON WIUM LIE, 34 *Opera Software*

Scandinavia is one of the most wired regions in the world. And within that realm, Håkon Wium Lie is a key player. As an early colleague of World Wide Web inventor Tim Berners-Lee, Lie has had a central role in the Web's evolution—particularly in relation to browsers. Working with Berners-Lee in Switzerland in 1994, Lie proposed the concept of cascading style sheets (CSS). CSS is a mechanism for adding typographical style (different fonts, color, spacing) to Web documents. Today, almost every major maker of Web browsers has adopted CSS—a big reason why Web sites look so much better than they did five years ago.

As the Web matured, Lie's career grew with it. When the World Wide Web Consortium (W3C) was organized to govern Web standards, Lie set up the W3C technical team in France. His chief concern was to maintain open (rather than proprietary) systems so the Web remained accessible to people using the widest array of access software. Lie has taken that passion for choice into the private sector as CTO of Oslo Web browser company Opera Software. Opera claims to be one of the most standards-compliant browser companies in the industry, and Lie's experience at W3C clearly helped them get that way.

MAGDALENA MIK, 25 *Walker Digital*

Among the auction sites burgeoning on the Web, Priceline.com is an early trendsetter. Its business of liquidating unsold airline seats and hotel rooms by letting travelers make low-ball bids online has pushed the company to a market valuation of $10 billion. To ensure a robust patent portfolio for his site, Priceline.com founder and vice chairman Jay Walker set up a think tank, Walker Digital, staffed with inventors and patent attorneys. Two years after joining the company, Magdalena Mik has her name on 44 pending U.S. patents for Priceline and other e-businesses. Her innovations include the Adaptive Marketing Program, in which Priceline adds a dollar amount to a customer's offer as a reward for an agreement to sign up for a credit card or some other service. Mik's latest e-brainstorm: a system enabling online shoppers to name the price they are willing to pay for merchandise, which they would pick up from a participating retailer.

Mik came to Walker Digital after receiving a BS in chemistry and completing one semester of law school (she's officially on a leave of absence). Though Polish is her native tongue, this immigrant to the United States at age 8 is fluent in commerce. She recently told Forbes that her inspiration was "the thought of being obscenely wealthy by the time I'm 30."

JONATHAN NELSON, 32 *Organic Online*

Not too long ago, marketing was pretty straightforward. The major channels were obvious. The techniques for working in television, radio and print were well established. And there wasn't much overlap among them. Proliferating cable networks and the Internet have obliterated this tidy world. Jonathan Nelson's job is to bring companies bewildered by the media meltdown into the 21st century.

Nelson began his career as a recording engineer. Today he is CEO of Organic Online, which manages advertising, public relations, marketing and research for such big-time clients as Gateway, Sun Microsystems and Starbucks. Since its 1993 founding, Organic has grown into a 350-person organization with offices in San Francisco, New York, Chicago and Brazil. Organic is known for innovative Web site design. But clients are beginning to demand data on the *impact* of their digital offerings—and Nelson is there to help. He is co-founder and chairman of Accrue Software, a San Francisco-based Web measurement and analysis software company. If Nelson can come up with ways to measure accurately the impact of Web marketing and devise effective strategies that tap the advantages of the medium, he will be heard from well into the next century.


JAMES PATRICK DAWSON

MICHAEL ROBERTSON, 32 *MP3.com*

The business of selling recorded music could be on the cusp of a complete makeover—and Michael Robertson is one of the main drivers of this change. Robertson is the force behind MP3.com, a Web site where recording artists bypass the marketing labyrinth of the recording companies and give their music away, via MP3 music-compression software.

MP3.com began in 1996 as the Z Company, which provided an online search engine. But when Robertson saw the MP3 software then being developed, he was dazzled by its potential. He promptly renamed his company and secured the rights to the MP3.com domain name. Over the next two years, the company grew from four employees to 35. In January it received a $10 million venture investment from Sequoia Capital. Soon after that, Tom Petty posted a song on Robertson's site to publicize the release of his new album—and the ball was rolling.

Music lovers' free ride can't last forever; legal battles over copyright and other issues are sure to erupt. But Robertson, named "one of the 100 most influential figures in the music industry" by the industry publication *BAM*, professes little worry about the feelings of recording company executives: "I don't have any friends in the music industry, so I don't have to worry about upsetting anybody."

MM

ANDREW SHAPIRO, 31

Aspen Institute Internet Policy Project

Many intellectuals writing about the Webolution tend toward either cheerleading or nay-saying. Carving out a third way is attorney/advocate Andrew Shapiro, director of the Aspen Institute Internet Policy Project, First Amendment Fellow at the Brennan Center for Justice at New York University Law School, and a senior advisor to the Markle Foundation. Shapiro first came to prominence writing about the Internet for as a student at Yale Law School. Since his admission to the New York State bar in 1996, he has been a fellow of Harvard Law School's Berkman Center for Internet & Society and at The Century Foundation. The latter supported the research and writing of —his recent tome on the politics of new media. Shapiro may best be known as co-founder of Technorealism, which seeks to define a middle ground between pro- and anti-technology thinking. Some critics find Technorealism banal; 's Steven Levy described the movement's founding statement as "vapid" and "muddled." Not everyone agrees. Mitch Kapor, founder of Lotus Development and the Electronic Frontier Foundation, says Shapiro has "enormous potential to make lasting contributions to society in the form of better integration and usefulness of computer and communications technology by the citizenry."

JOHN ROMERO, 30

Ion Storm

Almost all of the TR100 showed an early affinity for innovation. Perhaps none, however, blossomed earlier than John Romero, one of the creators of the popular video games Doom and Quake. Romero began writing games at 12 on an Apple IIe. His first paid games programming was at Origin Systems, creators of the Ultima series. He later took a job at Softdisk Publishing, where he met John Carmack, Adrian Carmack and Tom Hall. In the annals of popular culture, it was a fateful meeting. Together the four founded id software, where Romero was responsible for the design of the Doom series and Quake—games that set industry standards for their ability to simulate reality. These products have become so popular that Rolling Stone and Entertainment Weekly have hailed Romero as "the Steven Spielberg of gaming."

Although id had planned to begin on Quake II, Romero left to found Ion Storm and begin work on Daikatana, a first-person game that takes the player on a time-traveling quest for a mystical Japanese sword. The violent content of Doom, Quake and other computer games gives many observers qualms. But there is no question that they have been enormously influential in shaping the way teenagers spend their time—and perhaps how they think and feel. Like it or not, Romero's creations will shape the cultural landscape of the years to come.

FURNALD/GRAY

ERIC SILBERSTEIN, 23 *Idiom Technologies*

Wouldn't it be nice if everybody could *comprende* everybody else? *C'est impossible* on the Internet, which is growing most rapidly in the non-English-speaking world. Right now, Web businesses cope with the multiplicity of tongues by maintaining separate sites for each language group—a costly proposition. But leaving sites in English leaves some international surfers wondering *"Was ist das?"* That's a problem: Forrester Research reports that business Web users are three times as likely to buy when addressed in their own language. If Eric Silberstein has his way, the Internet will look *muy differente* in a few years: A single site will satisfy speakers of many languages. His company, Idiom Technologies, designs and markets "WorldServer" software, which tracks text that needs to be translated and then inserts translations into the multilingual site.

Silberstein's high-tech career began as CTO of ChipshotGolf.com, which sells golf merchandise online. In 1998 he founded Idiom, which recently received a total of $5.25 million from three different venture capital outfits. An early customer was Lycos, whose search engines attract global audiences. Angelo Santinelli, a principal at North Bridge Venture Partners, says Silberstein is certain to be "an impact player." *Domo arigato*, Mr. Silberstein.

JAGDEEP SINGH, 32 *Stanford University*

Today's telecommunications network is woven largely from fiber optics—glass threads that carry thousands of times more information than copper wires. The key to expanding this capacity even further lies in a technology called wavelength division multiplexing (WDM), which sends multiple signals down the same fiber, using different colors of light *(see "Wavelength Division Multiplexing," TR March/April 1999)*. WDM requires a sophisticated switch to direct multi-spectral traffic—and that's just what Jagdeep Singh created at his 1998 startup, Lightera Networks. Their invention, called the Core Director, was deemed so critical to WDM that last spring optical networking company Ciena bought Singh's year-and-a-half-old startup for a whopping $500 million.

Born in New Delhi to the family of a globetrotting diplomat, Singh landed in the United States and enrolled at the University of Maryland at 15. By 20 he was working for Hewlett-Packard and getting an introduction to telecommunications networking—a field primed for an explosion of demand. In 1993, he started AirSoft, which made software to improve the performance of wireless networks. He formed Lightera after selling AirSoft for $65 million. Now studying for a management degree at Stanford, Singh says he intends to switch from entrepreneur to captain of industry—building a company that will be a "lasting piece of the economy."

ALEX THOMPSON, 31 *Mixed Signals Technologies*

Interactive television has been an elusive goal almost as long as Alex Thompson has been alive. Although various schemes for real-time viewer feedback to TV programs have been demonstrated, none has secured a market foothold. A new system promoted by Thompson's company, Mixed Signals Technologies, could turn this dismal history around.

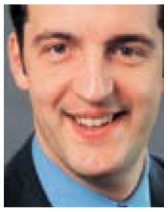
This system combines WebTV and Echostar set-top boxes and relies on program encoding equipment from Mixed Signals, which Thompson started in 1997. Mixed Signals inserts data for interactivity into the interval between broadcast video frames. Having developed the software, marketed as TV Link Creator, Thompson merged her firm with Ultech, which makes video-encoding hardware. The resulting ITV Dataflo System is becoming a standard tool for program developers, adding interactivity to TV game shows. Sony/Columbia TriStar Television, producer of "Wheel of Fortune" and "Jeopardy," liked the technology so much that parent company Sony Pictures is investing upwards of $13 million in Thompson's venture. Says Andy Kaplan, executive vice president of Columbia TriStar: "Alex has proven herself to be a leader in developing a cutting-edge technology which, we believe, will have a significant effect on our future business."

JERRY YANG, 29 *Yahoo!*

In book publishing, indexing is almost an afterthought. In electronic publishing, indexers are kings of the jungle. What started in 1993 on a Stanford grad student's home page as "Jerry's Guide to the World Wide Web"—a categorized list of sites, managed by a search engine—became "Yet Another Hierarchical Officious Oracle." Today, millions know it as Yahoo!, and it has become the second-most-visited site on the Web. Thanks to Jerry Yang's irreverent tone, and to top-notch programming by a fellow Stanford grad student, David Filo, Yahoo! had a huge part in making the Web accessible to people who didn't consider themselves computer-wise. After dropping out of grad school to take Yahoo! public, Yang has seen his worth in stock and options top $1 billion.

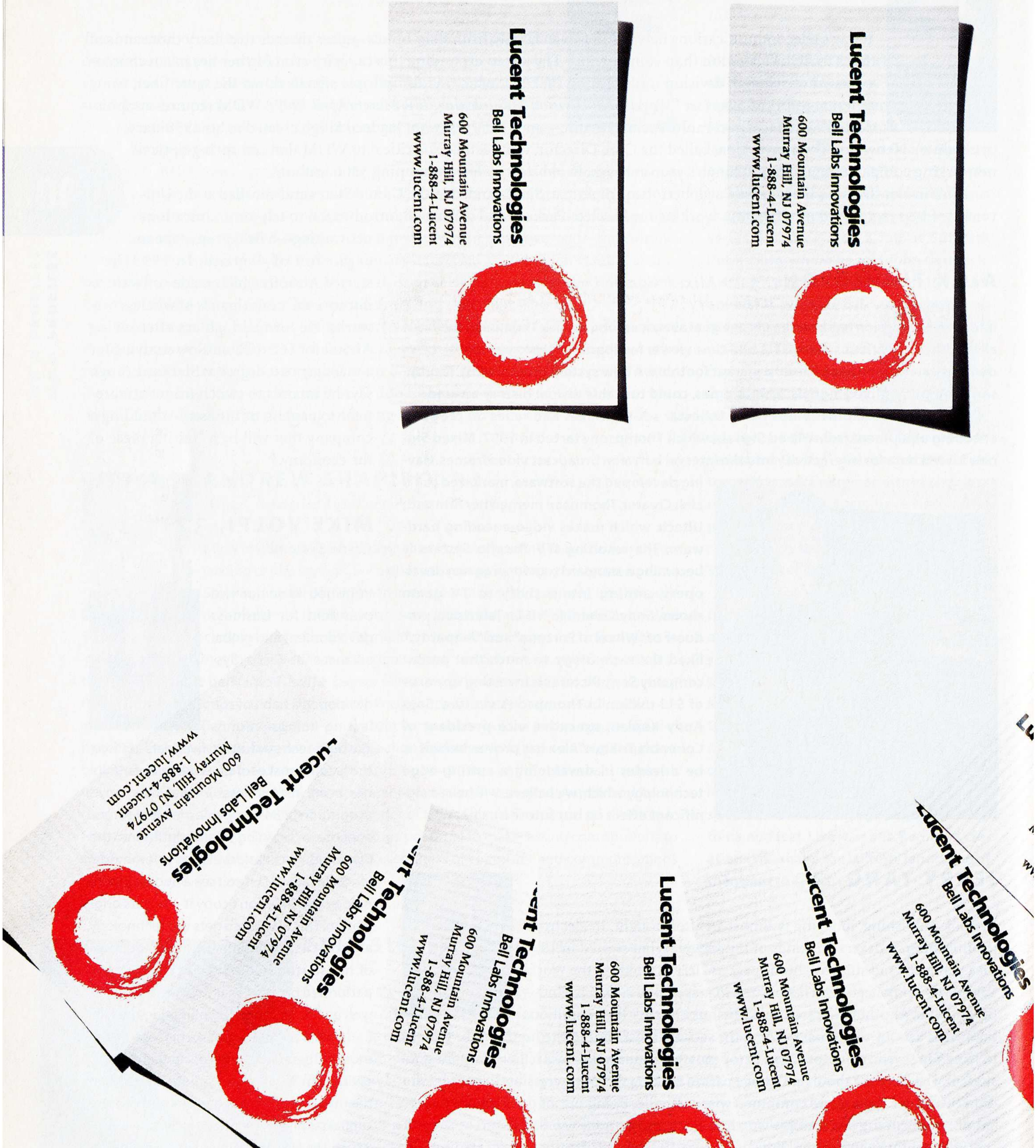
Born Chih-Yuan Yang in Taiwan, he was 10 when his family immigrated to Silicon Valley. Speaking recently on "The Motley Fool Radio Hour" about his astounding success, Yang said, "It's a dream come true, and in many ways it's what America is all about: Nowhere else in the world could people like me do something like this." Having described himself as "lazy" in grad school, now he is known at Yahoo! as Grumpy (his official title: Chief Yahoo) due to his fixation on staying ahead of the competition. Is Happy in his future?

MIKE VOLPI, 32
Cisco Systems



In his job as senior vice president for business development and global alliances at Cisco Systems, Mike Volpi has developed a habit of collecting things—things like high-tech startups. In five years at Cisco, the leading maker of network routers, Volpi has been instrumental in that company's acquisition of 34 companies. In his vigorous appetite for bringing smaller outfits into the Cisco fold, Volpi has developed a new model for corporate R&D: If you see a budding technology you like, don't copy it—buy its origination. This way, Cisco gets the technology ahead of its competition, and the founders of the startup get Cisco stock (which has performed phenomenally in recent years) as well as Cisco's powerful marketing muscle.

Volpi's acquisitions make him one of "the most influential dealmakers in technology, giving him, in many ways, more power than the myriad investment bankers and venture capitalists plying their trade in Silicon Valley," wrote last year. Born in Milan, raised in Tokyo and educated at U.S. universities (including an MBA from Stanford), Volpi demonstrates that innovations in ways of doing business can shape the technology landscape just as surely as dramatic new findings from the lab bench.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With unlimited potential.
We have the vision and know-how
to give you the network you need.
Along with the software and
service to make it all work.
Give us a call. We'd like that.

We make the things that make
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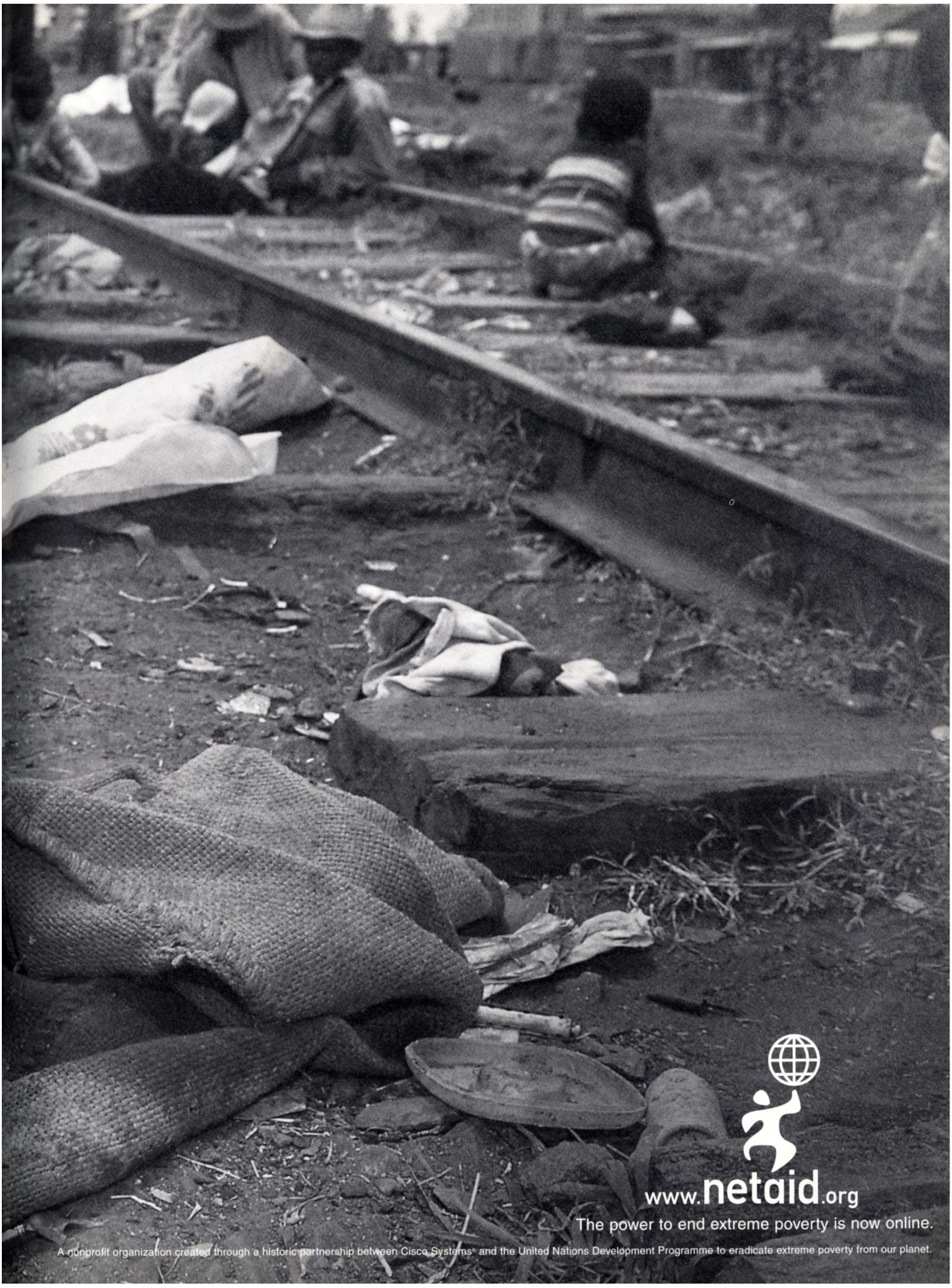
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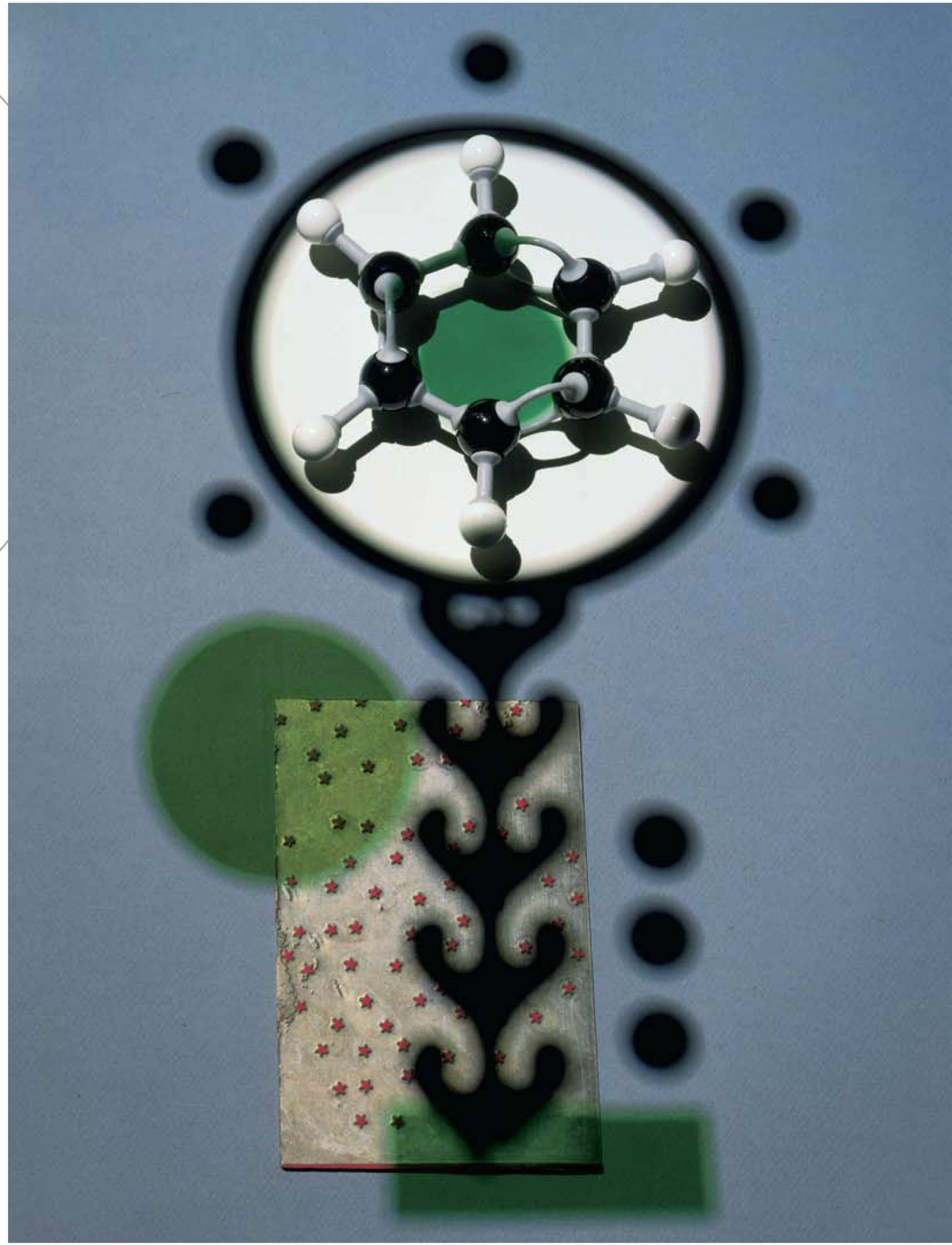
Materials

THE MOST HYPED TECHNOLOGY REGION IN THE WORLD MAY BE NAMED AFTER silicon, but materials research has hardly been the most glamorous of high-tech fields recently. Indeed, you could argue that there hasn't been a killer app based on a new material in decades. That could all be about to change if the TR100 who work in chemistry, physics and materials science have anything to say about it. Interviews with some of the brightest stars in the TR100 reveal their belief that improved materials are poised to change everything from computers to garbage bags.

What are the trends this stellar group sees? First and foremost is nanotechnology. Researchers are just learning how to assemble materials on the nanometer scale (a nanometer is a billionth of a meter, the size of a couple of large atoms). Nanotech, say the TR100, will make possible two key technological feats: building tiny communication and computing devices, and fabricating new materials—cheap plastics for example—with novel electronic and optical properties. These possibilities are opening up just in time, because as high-tech devices shrink, the limits of conventional materials are becoming clearer. But some of the TR100 say the new field of combinatorial chemistry could make discovering replacements far faster and more efficient.



Computers Invisible to the Naked Eye

"NANOTECH IS COMING TO FRUITION," SAYS BELL LABS' **Ralph Taylor-Smith**. In the same way that scientists in the last couple of decades learned to build devices on a micrometer scale, TR100 innovators are intent on engineering at the nanometer scale. "In the next 10 years, the buzzword 'nano' as a prefix will have blended into the background of science and general technology in the same way 'micro' has," predicts **Christopher Murray**, an IBM researcher. "At this point, no one would argue that there's [not] interesting stuff when you can push down into [the nanoscale] regime," says Murray. "But now we have the tools and the resources to really begin to understand and control materials by tailoring them at these dimensions—and that's the fun stuff."

By tailoring the nanostructure of materials, it is becoming possible to sew in desired electronic, optical and even chemical properties. "You can create the properties you want. You can design the materials from the ground up," says Taylor-Smith, who has invented new materials for optical-based information storage and for microscopic integrated circuits. Among her various projects, TR100 member **Jackie Ying** of MIT is making catalysts and membranes that could, because of their precise nanostructure, lead to safer and more effective pharmaceuticals. Meanwhile, Murray is fabricating ultra-high-density information storage media from magnetic "nanoparticles."

Much of the glory in the field will be reserved for what could be called "nanocomputing." One approach is to exploit quantum effects, the quirky rules that govern atoms and molecules, as the basis for immensely powerful new types of computers and communications devices. Researchers working with these effects are just about to bust out of theory and into the realm of nanoengineering. The goal, says Caltech's **Hideo Mabuchi**, "is to actually manipulate quantum mechanical effects rather than just observe them. We want to build the methodology to do engineering on a nanoscale." Mabuchi predicts that within three to five years researchers will make prototypes of "very simple" electronic devices that utilize quantum effects.

One Word...Plastics

THERE'S NO ARGUING WITH THE SUCCESS OF SILICON. IT'S THE foundation of everything from computer chips to optical devices to advanced sensors. Silicon and other inorganic compounds are the reason computers obey Moore's Law, and cell phones fit in your shirt pocket. Despite these impressive gains in performance, however, the underlying technology has remained the same for decades, and it's starting to look a little threadbare. Fabricating state-of-the-art semiconductor chips has become an unbelievably expensive game that only a few companies can play. In addition, there seem to be fundamental limits on how much smaller silicon transistors can get. To top it off, inorganic materials are brittle and fragile. Try dropping your expensive laptop and see how well it bounces back.

One answer to extending the current technology, say the TR100, is to find new materials that do the same job, better, faster and cheaper. Plastics, for one. Says **John Rogers** of Bell Labs: "There are a lot of things that it just doesn't make sense to make out of rigid, brittle materials like glass. It doesn't make sense to have cell phones or laptops with a glass screen that's so easily breakable. In a few years, you'll see devices that have similar functions but are made out of an unbreakable, bendable, flexible plastic." Such conformable electronic materials won't just appear in the screens of computers; they'll be everywhere in the computing machinery.

And not just in computers. **Yoel Fink** of MIT has similar ambitions for optical components. Engineers have learned to build very small optical devices for communications systems and other high-end applications. But these devices, like microelectronics, have clear limits, both in function and cost. By switching away from inorganic compounds, says Fink, you could make materials with desirable optical properties—the ability to selectively reflect a particular wavelength of light, for example—that are cheap enough to cover a wall. You also could make optical materials that could be swallowed and used for medical imaging. Fink has already come up with materials that fit the bill, using polymers that until now have found their main use "in the soles of shoes." By controlling the structure of these polymers at a nanoscale, Fink has turned them into a high-tech material he thinks "could revolutionize" the optics industry.

New Materials—By Chance

IF THERE IS CONSENSUS—AND THERE IS—AMONG THE TR100 ON the remarkable opportunities for materials in the next decade, there is disagreement about how to find the right stuff. At the moment, two approaches are vying for preeminence. Some of the TR100 aim to design a compound or material, typically using a computer to simulate the properties of different structures. Only after that, blueprint in hand, do they head into the lab to make it. This approach, known as "rational design," has for more than a decade been the holy grail for much of pharmaceutical and materials research. Cornell University's **Geoffrey Coates**, for one, is designing improved polymers by trying to understand how a catalyst affects a polymer's architecture—and hence its properties. The goal is to be able to make the catalyst structure that leads to just the polymer properties you want.

But some of the TR100 think there's a better approach. After years of trying, says UCLA's **Michael Deem**, "there's never been an [actual] drug designed on a computer." Adds **Isy Goldwasser**, in materials research "you can count on your hand the number of times that rational design has actually worked."

Deem and Goldwasser are among the TR100 who champion an entirely different strategy. Called combinatorial chemistry, it could make discovering new compounds and materials far faster and more efficient. Rather than painstakingly synthesizing and testing one sample at a time, the strategy involves making thousands of "combinations," then rapidly screening for the needle in the haystack. "In the short term—in the next 10 years—it's hard to see how rational design can match the output of combinatorial chemistry," says Goldwasser, who co-founded Symyx, the only startup dedicated solely to applying combinatorial approaches to discovering new materials. Symyx has deals with several large chemical and materials companies. These corporations don't necessarily want more complex and expensive materials, says Goldwasser; what they're after are catalysts that can make cheap and simple plastics with improved properties and functions. In other words, ways to make a cheaper, tougher, thinner garbage bag. TR

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DAVID CLEMMER, 34 *Indiana University*

Proteins are the workhorses of biology. In their active form, they are folded up into complex three-dimensional molecules, and understanding how folding happens is one of biology's enduring problems. Solving it could lead to safer and more effective drugs—even therapeutic proteins designed from scratch. In this search, an important new technology is David Clemmer's method of sorting molecules, including proteins, according to their shapes.

Rather than working with proteins in their normal, liquid state, as others typically do, Clemmer observes these molecules in the gas phase as they travel across an electrically charged space. Travel times can be used to construct a theoretical model of how the protein is configured and of the forces that determine how a protein folds.

Clemmer's method also could provide a screening technique for combinatorial chemistry—a drug discovery process that produces large mixtures of compounds. Methods for sorting mixtures of isomers (compounds that have the same mass but have different shapes and often different biological activity) are slow, relying on complex data that are difficult to interpret. Clemmer's approach makes it possible to sort large mixtures of isomers in seconds. Combined with other new drug-discovery methods, the reward will be a tremendous increase in the rate of screening molecules that have therapeutic potential.

CHRISTOPHER CUMMINS, 33 *MIT*

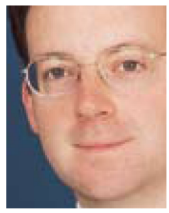
The search for as-yet-unknown reactions—and the accompanying technological potential—is an unending pursuit of inorganic chemistry. Despite years of exploration, there's plenty left to be discovered, a fact that Kit Cummins quickly points out.

Cummins, an assistant professor of chemistry at 27 and professor by 30, has already forged a world reputation for keen intuition and a deft touch in exploring new chemical ground. His most notable success: finding a way, at room temperature and pressure, to break apart the extremely strong triple bond that holds the atoms of a nitrogen molecule together. Such feats have so impressed the research community that one of the several leading scientists who nominated Cummins for the TR100 described him as "definitely Nobel Prize material."

For the moment, Cummins' work remains in the realm of fundamental research. But Cummins suggests that his efforts could lead to ways to better utilize small inorganic molecules such as dinitrogen oxide in the manufacturing of everything from pharmaceuticals to plastics.

GEOFFREY COATES, 33 *Cornell University*

It's hard to imagine a better raw material for plastics than carbon dioxide. It's cheap, nontoxic and ubiquitous. There's one problem, though: It's very stable and difficult to engage in chemical reactions. But Geoff Coates has invented a zinc-based catalyst that can make polycarbonates (a common plastic usually made from petroleum-based chemicals) using carbon dioxide as a starting point. The reaction is far more efficient than commercial polycarbonate processes, and the resulting plastic is biodegradable.



CHARLES HARRINGTON

This particular reaction may not revolutionize plastics production. After all, the low cost of oil makes it tough for other feedstocks to compete, even one as inexpensive and omnipresent as carbon dioxide. Yet there is little doubt Coates' impact will be felt in coming years in the chemical industry. That industry has long relied on discovering catalysts through laborious trial-and-error methods. One of Coates' ambitions is to rationally design catalytic structures to produce desirable polymers. "My dream," he says, "is to be able to sit at a computer and design a catalyst, then go to the lab and make it."

If he's able eventually to make that dream come true, the result could be more efficient manufacturing processes—and at the same time a cleaner environment. The future of the chemical industry will turn on whether it can meet both criteria. Look for Geoff Coates to help it.

CHARLIE POWELL

MICHAEL DEEM, 30 *University of California, Los Angeles*

Combinatorial chemistry is a radical departure from the way researchers have traditionally identified new drugs and materials. Rather than painstakingly making and testing compounds one at a time, in combinatorial chemistry you make hundreds of thousands—even millions—of variations at the same time, then screen to find the winners. Michael Deem is working to improve the odds in this high-tech game of chance.

By making an analogy between a computer simulation technique called Monte Carlo and combinatorial chemistry, Deem has provided a way to search more efficiently and broadly for new compounds. In general, Monte Carlo simulations are a powerful technique to sample data, using an algorithm that takes random "walks" among large datasets. Taking advantage of his chemical engineering background, Deem has developed "biased" Monte Carlo techniques that allow combinatorial chemists to greatly expand their searches, with the computer selecting the most promising paths.

Among other research projects, Deem is helping advance a new field called protein molecular evolution. "It's basically combinatorial chemistry for proteins," says Deem. The payoff could be a powerful new technique for finding protein-based therapeutics.

YOEL FINK, 33 *MIT*


FURNALD/GRAY

It's an invention that forces you to rethink one of man's most basic tools: the mirror. No, it's not a new vanity item. The "perfect mirror" Yoel Fink invented last year as a graduate student at MIT could mean radical new ways of directing and manipulating light. Potential applications range from a flexible light guide for delivering laser light to a specific internal organ, to new devices for optical communications, to coatings for windows that efficiently reflect heat while being transparent.

Fink's mirror combines the best property of the everyday metallic mirror—its ability to reflect light from all directions—with those of highly specialized dielectric mirrors, widely used in photonics. Like other dielectric mirrors, Fink's devices can be tuned to reflect only certain wavelengths of light with high efficiency. But Fink found a way to layer the dielectric material so that the mirror can reflect this light from all angles; other dielectric mirrors can't. What's more, his techniques for building these "perfect mirrors" are so general the devices can be made from a wide range of materials, including polymers.

Indeed, Fink is trying to exploit a class of polymers, called block copolymers, to create self-organizing optical components. MIT materials science professor Robert Rose says enthusiastically that "Yoel's approach using soft materials which can be processed inexpensively to form conformable reflectors may bring vast new markets into play."

ISY GOLDWASSER, 29

Symyx

Materials research used to be laborious. That was before Symyx—a company that is speeding up the discovery of new materials by applying the methods of combinatorial chemistry. Combinatorial chemistry involves synthesizing a large array of compounds simultaneously, then using innovative screens to pick out the winners—materials with desirable properties such as the ability to act as a catalyst.

Symyx, a 1994 startup, is the first company specifically devoted to using this process to replace trial-and-error methods in materials discovery. In the last several years, the company has raised millions in private and venture backing and has signed partnerships with a who's who of top chemical and materials companies. Much of the credit goes to Isy Goldwasser, Symyx's co-founder and vice president of business development until he was promoted to president and COO last year.

The potential of combinatorial chemistry? Shortened timescales for finding new materials, and the ability to search a broader range of possibilities. When Goldwasser was hired as the company's first employee, he says, "people thought we were crazy and we would never be able to do what we aimed to do, but we are proving them wrong."

AMIT GOYAL, 34

Oak Ridge National Laboratory

Remember high-temperature superconductors? These high-tech darlings of the late 1980s brought a Nobel Prize to their discoverers and generated endless hype about how their near-perfect conduction of electricity would revolutionize energy transmission. Well, it hasn't happened—at least not yet. One big obstacle has been the difficulty of forming flexible, long superconducting wires that can carry large amounts of current.

Amit Goyal, an Indian-born materials scientist, may have found a way over this hurdle. His contribution: growing thin layers of ceramic superconductors on a polycrystalline metal template, using the highly aligned metal to line up grains of the superconductors. The resulting structure of the superconductor resembles a single crystal, and the method has allowed Goyal and his co-workers at Oak Ridge National Laboratory to form superconducting wires capable of very high current densities.

That might—might—be enough for superconductors to fulfill their delayed promise. Within several years, says Goyal, high-temperature superconductors in wires for transmission cables and transformers could be a reality. If you sold all your stocks in companies with the word "superconductor" in their name, Amit Goyal might make you regret it.

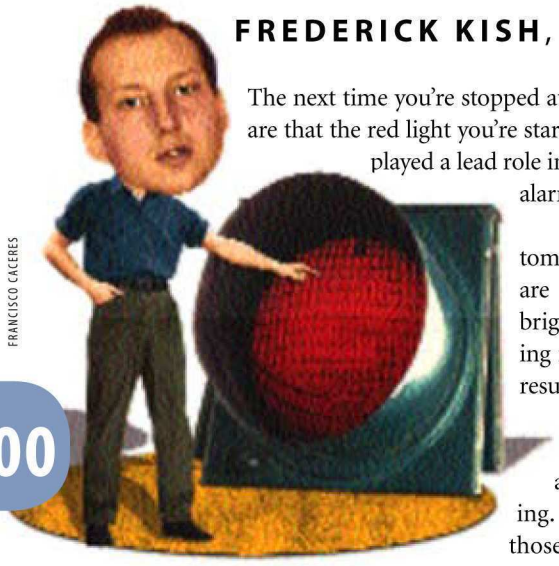
NICOLA HILL, 30

University of California, Santa Barbara

Nicola Hill's work shows how little space sometimes separates research and commercial application. Her work is in very basic research: fundamental physics and theoretical chemistry. Yet it centers on a growing field called "spintronics" that attempts to exploit the spin of electrons in magnetic fields as a means of information storage. Spintronics remains in its early stages, but one day it could have exciting applications for ultra-high density magnetic data storage, even powerful quantum computers. "But even if it didn't turn out to be all that practical, the physics is so exciting, it would never be a lost effort," Hill says.

Hill's research skills, intellect, and the gracious way she serves as a role model for young women in physics and materials science combine to make her an innovator to watch. She has started an "ambitious new research program in the theory of magnetic nanostructures, a field which holds great promise for its potential to revolutionize technologies such as magnetic data storage, next generation computers and magneto-electronic devices," says Fred Lange, chairman of the materials science department at UC, Santa Barbara.

FREDERICK KISH, 33 *Hewlett-Packard*


FRANCISCO CACERES

The next time you're stopped at the new traffic light on the corner, give a little thought to Fred Kish. Chances are that the red light you're staring at gets its brightness and color from the light-emitting diodes (LEDs) Kish played a lead role in inventing. Kish is one of the big reasons LEDs aren't just for wristwatches and alarm clocks anymore.

When Kish joined HP in 1992, the company was struggling to convince customers to use its LEDs in a wide range of devices. The advantage was obvious: LEDs are solid-state devices that don't burn out. The existing LEDs, however, weren't bright enough to compete with conventional lighting. Kish changed that by bonding red-orange-yellow LED semiconductor wafers on a transparent substrate. The results were the highest-performance red-orange-yellow LEDs ever produced.

The invention propelled HP's high-brightness LED products into a multimillion-dollar business. Most recently, HP and Philips Lighting formed a $150 million LED venture to compete head-to-head with conventional lighting. If LEDs do indeed light up our lives, it will be fair to say that Kish was one of those who struck the spark.

HIDEO MABUCHI, 28
California Institute of Technology

Consider two facts: 1) Hideo Mabuchi is the only Caltech graduate student in physics in the last decade to be offered a professorship before he received his doctorate; 2) Nobelist David Baltimore, president of Caltech, says: "Make no mistake: Professor Mabuchi's sights are set at nothing less than changing the world."

Mabuchi's plan to change the world leads through the quantum computer. A small but growing group of physicists hope to manipulate the quantum effects that govern the world of atoms to build powerful computers and communications devices. One hurdle to building even simple quantum devices is that experimentalists have been forced to observe quantum effects in tightly controlled systems, counting themselves lucky if they can catch even a fleeting glimpse of these phenomena. Mabuchi is working to change that.

He has conceived and performed experiments that measure quantum effects in real time in an open system, creating what he calls "realtime movies" of the interaction of an atom and photon. In his next experiments, he will try to control quantum interactions using this real-time feedback. That kind of control could be a first step toward making quantum devices a reality.

SHOKO MANAKO, 33 *NEC Corp.*

In March, Shoko Manako was named a "Young Researcher of the Year" by the Japan Society of Applied Physics. The purpose of the award is to encourage young Japanese scientists in their work. Then again, given the success Manako has achieved, she may not need much encouragement.

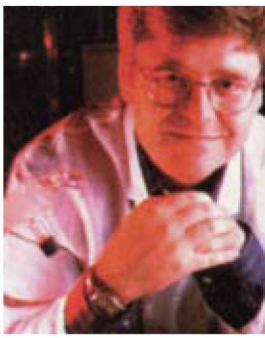
After graduating from Toho University in 1989, Manako went to work on new synthesis methods for high-temperature superconductors. She presented a paper based on that work to a 1989 meeting of the Society of Applied Physics and her career took off. Since then, Manako has spearheaded research at NEC to further develop next-generation methods using electron beams (rather than light) to etch features onto computer chips.

In particular, Manako has fabricated patterns in a polymer resist (the material used to pattern semiconductor chips) as small as 7 nanometers wide. "This width is the most narrow resist pattern that has ever been obtained in the world, and gives a way to a new device such as a quantum-effect device," says Kiminari Shinagawa of Toho University.

CHRISTOPHER MURRAY, 32 *IBM*

Fabricating devices on the nanometer scale (a nanometer is a billionth of a meter) could mean fast, cheap and powerful computers and microelectronics able to store vast amounts of data. But building anything on that scale is no small task. A new and promising approach is to take advantage of chemistry's remarkable talent for assembling materials with molecular precision. Chris Murray has helped pioneer "chemical assembly" and, in starting up a research effort at IBM, is hoping to use it to revolutionize magnetic data storage.

At IBM, Murray is cooking up solutions for fabricating arrays of magnetic nanoparticles. He has succeeded in assembling precisely structured thin films of magnetic materials that can be read by the sensors of a conventional hard drive. The ultra-high-density storage medium will help test just how small features in conventional magnetic technology can become and still function.



Whether the work will pay off in a widely used new data storage medium that can be assembled cheaply and precisely remains "uncertain," he says. But it seems clear that, given Murray's skills as a materials chemist and his instincts for surrounding himself with top engineering talent, he has a good shot at making it happen—and if he does, the payoff for the computers of tomorrow will be very large indeed.

DIANNE NEWMAN, 27 *Harvard Medical School*

Dianne Newman did not plan a career in geomicrobiology—she expected to be a lawyer. But one day in a lab, someone handed her a bottle of a yellowish substance. "I had some materials science background, and I managed to find out the bacteria in the bottle were producing the yellow stuff—and it was arsenic trisulfide," she recalls. "That was it—I was hooked."


DAVID SMALL

Today, Newman, who becomes an assistant professor at Caltech in January, is a leader in geomicrobiology, a new field that draws from microbiology, environmental science and geochemistry. Her goal, she says, is to figure out how microorganisms "shape the chemistry of their environment." The reward could be microorganisms with unique metabolic properties useful for making new medicines—or cleaning up toxic waste sites.

Newman's research in geomicrobiology could also produce clues to interpreting evolutionary and geological records. According to Caltech president David Baltimore, who nominated Newman for the TR100, she has "positioned herself, perhaps uniquely, to lead in the development of a new and exciting discipline for understanding the geologic evolution of the Earth and the interactions between the biosphere and the Earth."

LYNN RUSSELL, 30 *Princeton University*


ALYS LONGWORTH

One of the most important technological questions facing our species is: How much have we already affected the natural warming and cooling of the Earth? Many researchers argue that global temperature change is already well under way. A few others argue that too little is known to reach conclusions or make policy changes.

Clearly, there is an urgent need for more and better data. In particular, we need to measure accurately the complex atmospheric systems that help set global temperatures. One innovator in this area is Lynn Russell, whose research centers on how aerosols (vaporous suspensions of liquid or solid particles) from automobile emissions and other air pollution affect climate.

Russell is distinguished among her peers partly by her capacity for designing better systems of instrumentation. She has, for example, pioneered the use of automated instruments aboard remote-controlled airplanes to gather aerosol data. Her own measurements could lead to better understanding of how long aerosol particles survive in the atmosphere—a key to determining their impact on climate. Russell's research will provide the data needed for all of us to make cooler and less politicized decisions about global warming.

JOHN ROGERS, 32
Lucent Technologies' Bell Labs

Silicon and related inorganic compounds are the bedrock of microelectronics. They're great for speeding electrons in computers, and they're increasingly used as building blocks for tiny sensors and other micromachines. But these inorganic materials are brittle and fragile and are typically formed on perfectly flat surfaces. It would open up remarkable technological vistas if integrated circuits could be made directly on a curved surface or out of flexible materials. John Rogers, a physical chemist, is hoping to make this vision real.

Rogers has developed a series of novel fabrication techniques to make transistors from organic polymers, and integrated circuits on curved surfaces. The results are piling up: plastic transistors with features 100 nanometers across—half the size of those in a state-of-the-art semiconductor chip—and an optical fiber whose curved surface has been tattooed with microelectronics that can be used to control the fiber's optical properties. The new transistors could be utilized in a flexible computer display consisting of a thin sheet of plastic.

William Brinkman, a VP at Bell Labs, describes Rogers as "broadly interested and driven by scientific curiosity, yet always keeping an eye on possible technological applications."

DANIEL SCHRAG, 33 *Harvard University*

Recent droughts and floods have raised concerns about global warming, El Niño, and their impact on our planet. To predict future weather requires improved understanding of climatic variability over time, and of the role of technology in changing the climate. To get there we need better methods for measuring how Earth's climate has changed over geological time. A leader in that effort is Daniel Schrag, who calls himself a "geochemical oceanographer."

Schrag has shown tremendous technological ingenuity by devising methods for collecting massive amounts of geochemical data and analyzing it cheaply and accurately. "For one-third the cost, we can do 100 times as many analyses about 10 times more precisely," says Schrag of one of his methods. Using this and other techniques, he measured the temperature and composition of the ocean during the last ice age, and extracted information from corals on how Pacific Ocean dynamics have changed over time. Such information has, among other things, produced insights into the recent strong and frequent El Niño events.

Our future could depend on our ability to understand the impact of technology on the environment. Schrag will likely be a leader in inventing techniques to promote that understanding.

CHRISTINE SMITH, 28

University of California, Davis

In many fields of technology, collaboration across disciplines is growing rapidly in importance. The people who lead these large-scale collaborations need strong political skills to identify, organize and raise funds for promising projects. It also helps enormously if they are technologists who speak the same language as the project partners. Fitting that role is materials scientist Christine Smith. Still in her 20s, she has already paved the way for productive research collaborations among thousands of people.

As a graduate student at the University of California, Davis, Smith came up with a laser-based method of designing nanocrystals, but she realized she needed facilities at Lawrence Livermore National Laboratory. So she initiated a still-thriving partnership between students and researchers at these two institutions. She later repeated this feat on a larger scale at the University of California (UC), fostering collaborations among thousands of employees at UC's nine campuses, the three national labs it manages, government agencies and corporations.

Partnerships established through Smith's programs have led to advances in polymer design and human genomics. "Equally at home with high-level scientists and venture capitalists" as a former colleague remarked, Smith could be an important catalyst in the formation of many future collaborations.

STEPHANIE VIERKÖTTER, 33 *Quantum Magnetics*

Polymer composites are stronger, cheaper and lighter than metals. They could be used to make fuel-efficient, rust-resistant cars and airplanes and to retrofit aging bridges. Yet if they're so good, why aren't they used more widely? One reason: industry lacks inexpensive, nondestructive evaluation methods for testing the stresses and strains on these materials when they are in place. Hoping to reduce the stress in this area is Stephanie Vierkötter.

Vierkötter aims to turn a sophisticated lab instrument for measuring something called nuclear quadrupole resonance (NQR) into a practical technology that can map the response of composites under varying loads. If she succeeds, the NQR-based gauge could help engineers monitor a composite to determine if it's still safe.

Vierkötter is also developing an NQR-based system to detect TNT in plastic-cased landmines. By reading the explosive's chemical signature, this system would work better than conventional metal detectors, which mistake nails and other metal objects for mines. One hallmark of an innovator is the ability to take an exotic lab technology, see how it could change the world, and bring it forth into the market. Vierkötter has that trait in abundance.

RALPH TAYLOR-SMITH, 34 *Lucent Technologies' Bell Labs*

One key to improving the speed and bandwidth of communications systems is coming up with new materials that have just the right combination of electronic and optical properties. It's even better these days if the materials can be tailored on the nanoscale. But synthesizing "nanostructures" for different materials is an expensive, time-consuming process. Those who can find better ways to do this crucial job will be among the heroes of the Information Age.

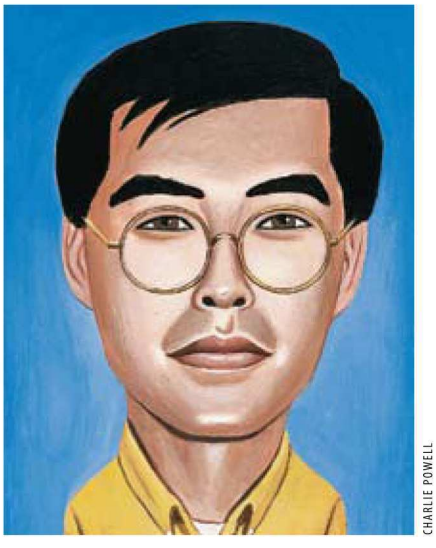
One budding techno-hero is Ralph Taylor-Smith, who has devised an efficient way to produce nanocomposites of organic and inorganic components, a process he calls "application-specific materials design." The secret of the process is a generic template Taylor-Smith has assembled from organic polymers and inorganic materials. By substituting different components, he can custom-design nanomaterials for specific applications. Taylor-Smith has already invented a variety of new materials, including one suitable for optical-based information storage.

Taylor-Smith, a chemical engineer, has also won two Lucent Environmental Heroes Awards for efforts to reduce the environmental impact of manufactured products and manufacturing processes.

KEN-TSUNG WONG, 33 *National Taiwan University*

Organic chemistry is like gardening: There's a large body of factual knowledge to be acquired, but mastering that knowledge doesn't make you great. There's also that puzzling intangible thing known as a "green thumb"—some folks have it, some don't. Ken-Tsung Wong has an "organic chemist's green thumb," says Scott Denmark, who was one of Wong's teachers during his graduate work at the University of Illinois at Urbana-Champaign. Adds Denmark, "He has a highly developed instinct for how to make chemical reactions work, one unparalleled in my experience. It's a talent that's hard to teach or articulate in rational terms."

The blooms that Wong's green thumb brings up could have an impact on several industries. As a postdoc, Wong identified new catalysts for reactions that, if applied, could enable the pharmaceutical industry to prepare therapeutic agents more efficiently. At National Taiwan University, Wong uses his green thumb in another fertile field: designing "molecular wires," which could be used in the nanocomputers of the future. His efforts have already led to compounds with promising photo- and electrochemical properties.



CHARLIE POWELL

FURNALD/GRAY

JACKIE YING, 33 *MIT*

Jackie Ying thinks applications. It doesn't take very long in a conversation with her before she makes clear she's more interested in explaining uses of her nanoscale materials than in discussing arcane details of their chemistry. An associate professor who has already distinguished herself in the traditionally male domain of chemical engineering, Ying comes alive as she ticks off the potential benefits of her precisely tailored nanomaterials: safer pharmaceuticals, more efficient processes for making industrial chemicals, better catalysts to cut air pollution from automobiles. She adds that her group is also interested in using the materials to make nanoscale wires for microelectronics and "smart" drug-delivery systems.

The list is remarkably broad, but make no mistake, these aren't fantasies. Ying has developed elegant ways to tailor materials with nanoscale precision, using self-assembled organic templates as the scaffolding. She has, for example, synthesized catalytic materials with intricate—but well-defined—networks of pores. These nanopores give access to the catalytic surface to specifically sized or shaped molecules; thus the catalysts can be used for very selective reactions, such as producing the desired form of a compound that comes in several variants, which could mean safer and more effective therapeutics.

That's only one possible benefit. The simplicity and flexibility of her approaches mean they can be applied in a wide variety of industrial contexts. Nanotechnology will be one of the key economic areas of the next century. And in that field Jackie Ying will be a leader.

Wearing Two Hats

Academia or Industry used to be a tough choice. These days, the TR100 say: "Why choose?"

TR100

ACADEMIA OR INDUSTRY? THEME

Not too long ago (say 15 years), the boundary between academic and industrial careers was still pretty clear. For a newly minted PhD, the university offered creative freedom, the private sector greater resources and better remuneration. People tended to choose one path or the other and stick to it. Boy, have things changed. The careers of the TR100 show that today's most successful young people don't see academia and industry as an either/or proposition any longer. These days, innovators want it both ways.

Take professor-entrepreneur Mark Prausnitz, whose double life is playing out on the Georgia Tech campus and in the boardroom of Redeon, a startup he co-founded. "It's stressful," concedes Prausnitz. "The difficulty comes in needing to master two very different worlds." As a young professor, Prausnitz is set to publish or perish, teach and write grant proposals. In his work with Redeon, which is looking to commercialize a new drug-delivery method he helped invent, Prausnitz needs to learn about patents and IPOs. Prausnitz says he puts up with the stress because working in both contexts is an engineer's "ideal scenario": every lab advance helps the business, and the business validates the research's practical importance.

Some of the TR100 see clear benefits on one side or the other of this new equation. Joseph Hellerstein, who co-founded middleware firm Cohera but kept his day job in the University of California, Berkeley computer science department, believes that, in the long run, the university is the place to be. "By staying at a company long-term you have less opportunity for real impact—the rate of innovation necessarily slows down, you end up in management and being used as a marketer."

John Rogers says that stereotype doesn't fit, at least not where he works: in the physical research division of Bell Labs. Having enjoyed both a brilliant start on an academic career and the building of a successful startup, Rogers was awestruck by the "incredible resources" and intellectual freedoms he's found at a big corporate research lab. "If you're really into the technology, there's no better place," Rogers says.

Although each *modus vivendi* has its partisans, many look to make the most of each environment in turn. For instance, at 25, Gregg Favalora folded his cards and left a Harvard PhD on the table to work full time on 3-D computer visualization. He hopes his startup, Actuality Systems, will make him wealthy, but says money isn't the goal—it's a means to an end that, ironically, looks a lot like the university setting he emerged from. "People my age talk about 'making it rich,'" Favalora says, "so that down the line we'll be free to pursue riskier and more cutting-edge endeavors." Favalora envisions underwriting "a sort of invention lab" where people "think up crazy technologies."

And some other successful entrepreneurs, rather than inventing their own think tanks, simply head back to existing campuses. Jagdeep Singh, who made a bundle on telecom company Lightera, returned to Stanford for a second master's degree. For Singh, school means the leisure to steep in big ideas. "I want to give myself time to step back from the trees and identify a really massive emerging problem," he says.

One member of the TR100, Andrew Shapiro, believes that the obliteration of existing boundaries is itself due to technology. In his book *The Control Revolution*, Shapiro argues that improved access to information has shifted power from institutions to individuals, leading to a "hybridization of intellectual pursuit and commercialization." Shapiro is a case in point: He's a Columbia law professor, technology pundit, policy-maker and entrepreneur. Shapiro's advice: "The job description may not exist. So define it yourself. The entity you want to work with may not exist. So create it. And don't be afraid to do more than one thing at a time." The TR100 certainly aren't.

—Brad Stenger

“

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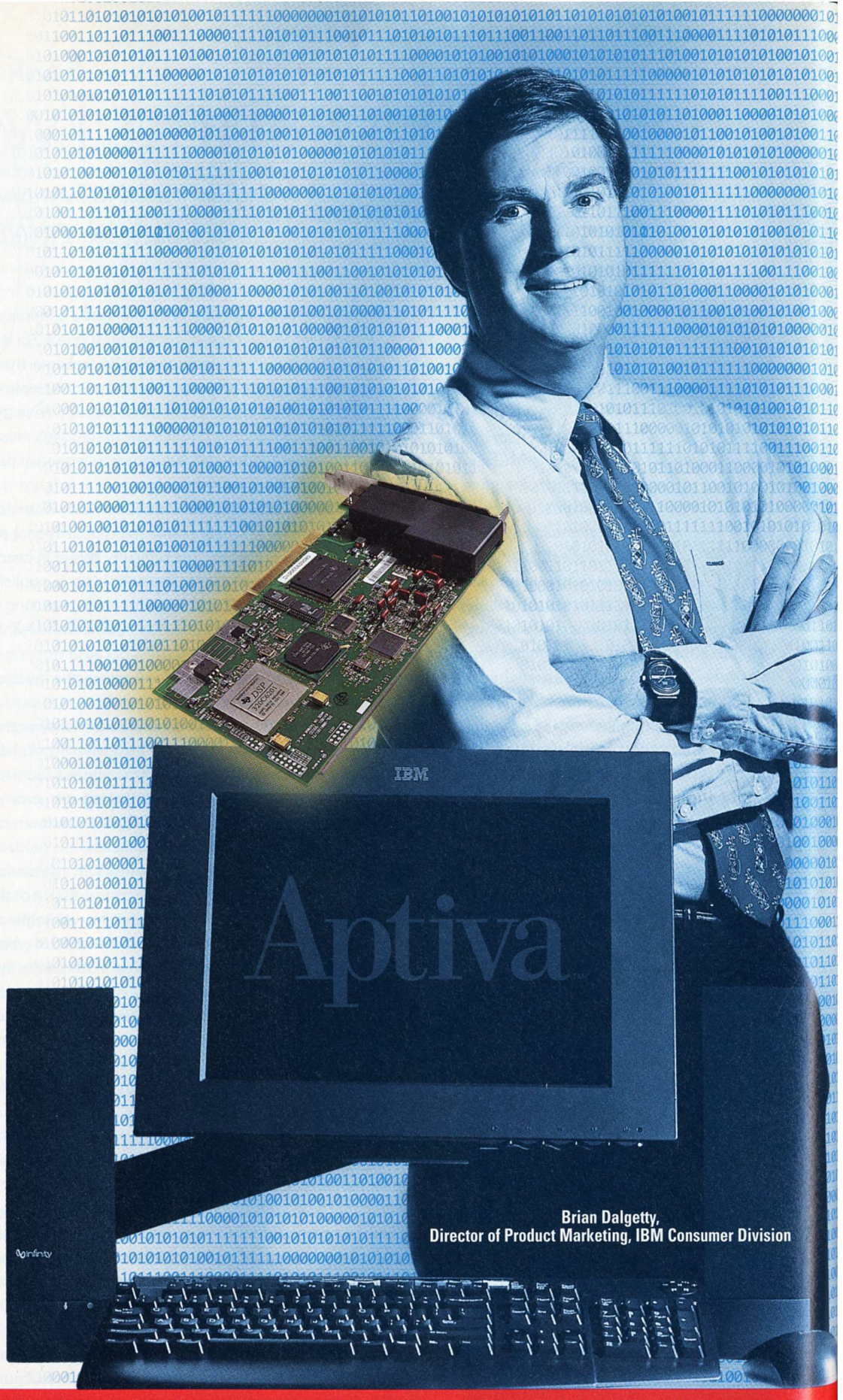

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Hardware

AMID THE PERVASIVE HAPPY TALK ABOUT THE NEW INTERNET ECONOMY, it's easy to forget that information technology ultimately requires actual tangible *stuff:* circuit chips, optical fibers, switches and all kinds of other hardware. The hardware cohort of the TR100 works on this side of the digital future, pushing atoms and molecules around to make it possible for all those databases to get filled up, e-mails to be sent, and online transactions to be processed.

From chips to robots, hardware is where the information world gets real. And in that arena, the TR100 foresee at least three critical trends. The first is that robots will be everywhere (although not necessarily in the cartoonish form we recognize from the movies). The second and third are twin trends emerging from the fact that it's becoming increasingly difficult for computers to keep doubling their power and reducing their cost, as they have for the last couple of decades. One trend is the ingenious modification of silicon-based technologies in an all-out effort to sustain the current rate of progress. The second is the emergence of some exotic new paradigms for computing that rely on materials far beyond silicon. DNA, anyone?

Robots, Robots Everywhere

SCIENCE FICTION HAS CREATED A POWERFUL IMAGE OF ROBOTS that look and act human. But the TR100 don't think that's the future for most robotics. Our young innovators say robots will look even less like humans than they do now and will take on a remarkable variety of shapes and sizes, forms dictated by their tasks. "Why do robots need to be humanoid?" asks **Maja Mataric**, director of the Robot Research Laboratory at the University of Southern California. "It's a bad idea in the real world." Instead, she says, robots should take on the configurations they need to get a particular job done, such as insect-like machines for navigating uneven ground in search of land mines.

Rather than looking forward to mechanical humans, the TR100 say we should pay more attention to the robots that already surround us. "High-tech robots appear in common places, but people don't think of them as robots," says **Akhil Madhani** of Walt Disney Imagineering. **Mark Yim**, of Xerox's Palo Alto Research Center, agrees that the future lies in robots that don't fit our preconceptions. Yim puts a new spin on the often-discussed trend of computers being embedded in everyday objects, from cars to toasters. The injection of computing power into these mechanical objects actually makes them "hidden robots," Yim argues, and he claims such creations "will play more and more significant roles in our lives, whether we realize it or not."

In order for robots to play enhanced roles in our world, the TR100 say, there will have to be some specific technological advances in two main components of robotic devices: sensors (which provide data about the machine's environment) and actuators (which make physical things happen). Today's robots are virtually "blind and deaf" because of the lack of sophisticated sensors, says Mataric. Madhani says he, on the other hand, is frustrated because he "can't get actuators that do more: more power in a smaller space, more speed, and more accuracy." The coming decade will see rapid advances on both fronts.

Extending the Lifetime of Silicon

THE RAPID DEVELOPMENT OF ROBOTICS (ALONG WITH ALMOST every other area of information technology) has depended on the continuing increases in computational power and equally tremendous decreases in the cost needed to obtain that power. The semiconductor industry has been riding Moore's Law: the rule of thumb that every 18 months advancing technology will double the number of transistors that can be squeezed onto a chip. However, there's growing concern among computing experts that Moore's Law might peter out within the next decade or two; at some point it may become impossible to pack any more circuitry onto a silicon chip.

The end of Moore's Law could have dire consequences. But the TR100 say they see two trends emerging that could extend its lifespan. The first is the emergence of ingenious ways to modify the existing silicon technology. "My guess is that we will figure out how to get around limitations with silicon-based processors in the next 10 to 15 years," says **Todd Mowry** of Carnegie Mellon. "We may hit a speed bump, but I doubt we will hit a wall."

Mowry predicts dramatic improvements in processor speed and memory capacity, based on refining silicon technology. For instance, he envisions multiple processors residing on a single chip. Such a "multiprocessor" would have many of the advantages of current parallel-processing machines—and also be much easier to program than parallel processors are. Mowry also foresees dramatic improvements in silicon-based memory systems. He cites a project at Carnegie Mellon for endowing chips with dense, "nonvolatile" memory (the kind that doesn't evaporate when the power is switched off). "Think of it as putting the disk drive directly on the chip," he says. This could lead to gigabytes of memory on a single chip.

Mowry is only one of many grappling with the limits of silicon technology. ***Joe Jacobson***, of MIT's Media Lab, is contending with another problem silicon faces: For a chip to be of use, every transistor must work perfectly. That's a tall order, and it places severe constraints on manufacturing facilities. According to Jacobson, "currently, when a high-end chip line is brought up, yields are a few percent" because most of the chips have defective transistors. His solution: programmable interconnects that "allow you to reroute to only good transistors on the chip." This way, he says, yields will be "essentially 100 percent."

On Beyond Silicon

THOUGH SOME OF THE TR100 ENVISION SILICON-BASED TECHnologies continuing their rapid advance, others see another trend on the horizon: radical new materials supplanting silicon as the matrix of information technology. Many researchers, such as Stan Williams of Hewlett-Packard, believe silicon-based processors will begin to reach their fundamental limits within the next decade *(see "Computing After Silicon," TR September/October 1999)*. Members of the TR100 are among the leaders in developing a variety of exotic new technologies to replace silicon.

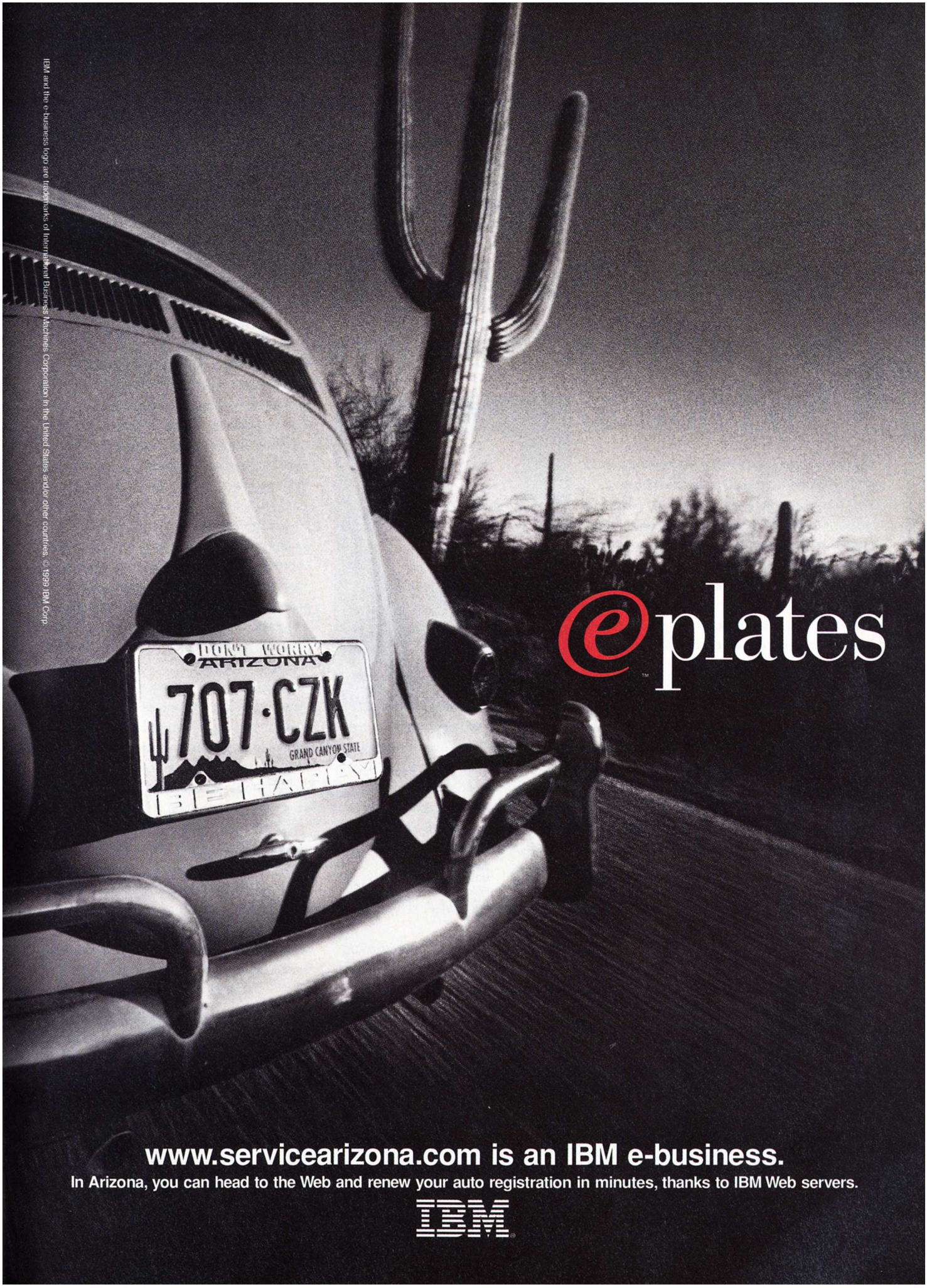
One of the most exotic is quantum computing, in which data are stored in the nuclear spins of individual atoms and molecules. The nonintuitive laws of quantum mechanics potentially allow for huge leaps in computational power. "Any new technology must generally exceed the previous technology in some [crucial functional aspect] by at least a factor of three, in order for it to be adopted," says **Isaac Chuang**, who is studying quantum computing at IBM's Almaden Research Center. "Quantum computers promise this and more, in theory—but have yet to deliver it in practice." Will quantum computing extend the regime of Moore's Law? The jury is still out, says Chuang: "Our experiments and others' have provided a few data points in the past two years, but it is too early for a definitive conclusion."

Even if quantum computing does not pan out, the future looks bright for alternatives to silicon. Chuang and others highlighted a variety of non-silicon-based methods, including the use of biological substances such as DNA for computing. One or more of these methods will almost certainly yield promising prototype computational systems within the next decade.

Print Out a PC

QUANTUM COMPUTING AND DNA COMPUTING INVOLVE RADICAL departures from the computers we're familiar with. Even in the absence of radical departures, some of the TR100 are looking beyond silicon. The Media Lab's Jacobson points out that although the cost of computing power has fallen through the floor as engineers cram more circuitry onto each sliver of semiconductor, the cost of a chip per unit area has remained about the same for 20 years. "This means that if I want to make large displays or electronics embedded in clothing, I run into a problem if I plan to use conventional chip technology," he says.

Jacobson predicts that in the not-too-distant future, it will be possible to print chips on a wide range of materials having little to do with silicon. Making this kind of technology widely available, he says, would open hardware design to a far larger audience. He envisions a community of do-it-yourselfers who would be chip design's equivalent of the "open-source" movement in software. "A printer that can print functioning PCs could do for hardware what desktop laser printers did for publishing." TR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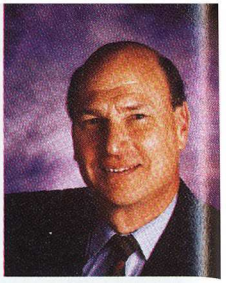

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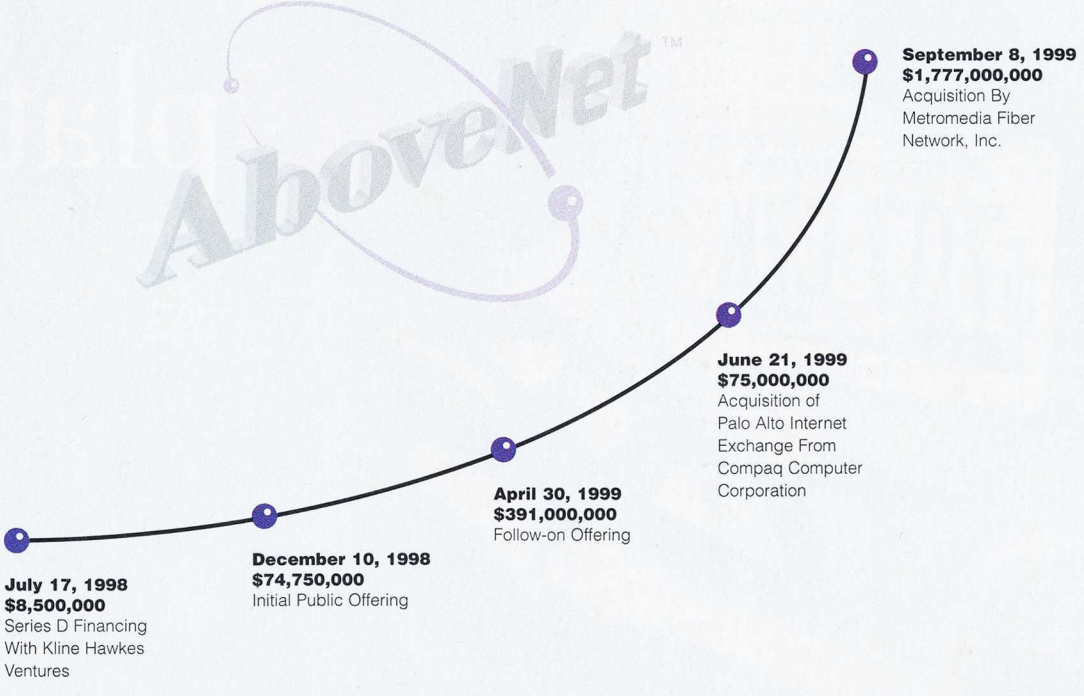

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PAUL BENDER, 33 *Qualcomm*

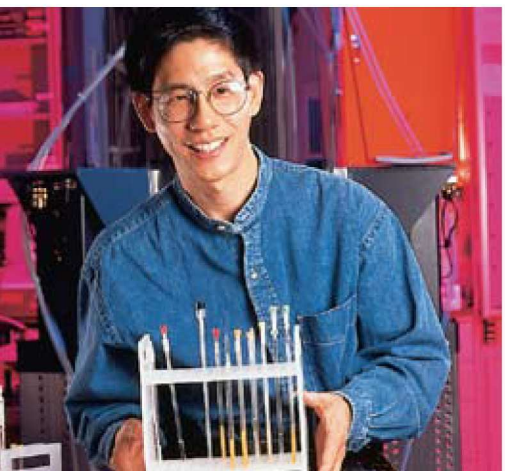
The last decade has seen cell phones and wireless communication blossom from a tool for privileged executives to something close to a necessity for almost everyone. But the revolutionary impact of this wireless world will come only when more bandwidth is available to provide video, Internet and other services. One of the folks at the forefront of the search for bandwidth is Paul Bender. After completing his doctorate at the University of California, San Diego, he joined Qualcomm and started working on projects to improve the quality of wireless communications. Using a protocol called Code Division Multiple Access (CDMA), Bender developed new equipment to take maximum advantage of it, including a sophisticated processing system on a single chip that reduced the mass and cost of cell phones. He currently leads a project to develop high-speed wireless data access with only the amount of spectrum currently used for a few voice users. Movie studios could soon transmit digital versions of their films to theaters using such technologies. Qualcomm is impressed with Bender's versatility. "What is remarkable is that he excels in four distinct areas of engineering: the design of hardware, the development of software, the creation of new and improved systems and the mathematical analyses of these systems," says Qualcomm vice chairman Andrew Viterbi.

ISAAC CHUANG, 30

IBM Almaden Research Center

Computers have been an industrial miracle for a couple of decades—becoming exponentially more powerful *and* cheaper. But miracles aren't forever, and it will soon become impossible to continue this trend with the current silicon-based technology. One possible solution is an entirely new model for computing, "quantum computing," in which data are encoded in the quantum spin of atoms and molecules. But what is intriguing in theory can be difficult in practice; quantum computing is no exception. The creative leaders who can reduce the concept of quantum computing to practice may go down in the history of technology. Isaac Chuang might be one of them.

While still a graduate student at Stanford, Chuang was one of the developers of a basic, two-bit quantum computer. Since then he's demonstrated that a quantum computer can run simple algorithms and perform database searches. He continues his work on the topic at IBM's Almaden Research Center, trying to scale up quantum computing. Some think Chuang could be one of the ones to move from vision to reality in this field. "His omnivorous curiosity, mastery of so many levels of description, and profound contributions really are exceptional," says a collaborator, MIT professor Neil Gershenfeld. "If anyone is going to turn quantum computing into a reality, it will be Ike."



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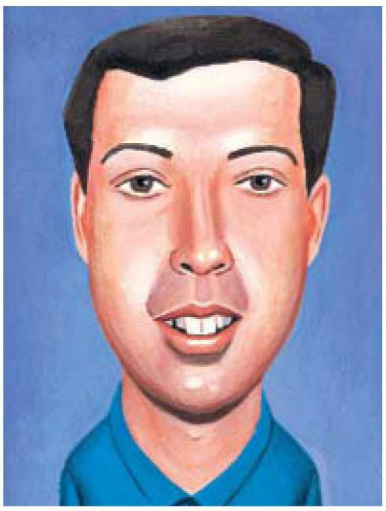


CHARLIE POWELL

GREGG FAVALORA, 25

Actuality Systems

Virtual reality (VR) is hot these days, because of its potential in entertainment, learning and research. However, the most advanced systems render three-dimensional reality in two dimensions. Gregg Favalora thinks three dimensions are better. He has been working on "three-dimensional" VR since his undergraduate days at Yale, where he developed a prototype exploiting lasers, lenses and mirrors to render images that are truly three-dimensional. Unlike conventional VR systems, Favalora's fictions occupy a volume of space: They can be walked around and viewed at almost any angle. He refined his concept as a graduate student at Harvard, then co-founded Actuality Systems and went on to win the 1997 MIT $50K Entrepreneurship Competition. The company is working on larger versions of its 3-D display, with the goal of producing a display that can be connected to a computer for applications ranging from pharmaceutical research to computer-assisted design. "I think great entrepreneurs must have three values: integrity, intelligence, and initiative," says Rob Ryan, founder of Ascend Communications and a mentor to Favalora. "Gregg possesses all three."

AMY FRANCETIC, 32 *Zowie Intertainment*

SANDRA FRANK

Young humans spend an awful lot of time playing with toys and, these days, an equally large amount playing computer-based games. The two areas would seem to offer a natural intersection. So far, though, there hasn't been much crossover. Amy Francetic, co-founder of Zowie Intertainment, hopes to change that with "smart toys." Zowie's "PlayZones," due in stores this fall, are toys that connect to a PC running accompanying software. The link allows children to use the software by playing with the toys: Moving the telescope mounted on a pirate ship in one PlayZone, for example, changes the view displayed on the computer screen. Francetic believes these toys will encourage the cooperative play that's common with conventional toys but rare for computer games. She brings to the company a background of developing CD-ROM games for Hasbro and Electronic Arts, as well as work at Interval Research, the research lab from which Zowie was spun off. "Her ability to inspire creative people to solve technical design problems will help her continually to uncover the strengths of emerging technology platforms," says Stewart Bonn, who worked with Francetic at Electronic Arts.

HELEN GREINER, 31 *IS Robotics*

These days, robots are typically used in limited, specialized roles. But if Helen Greiner and Colin Angle have anything to say about that, robots may soon be a more versatile and ubiquitous part of our lives. Greiner and Angle are two of the founders of IS Robotics. Working for the Defense Advanced Research Projects Agency and the Office of Naval Research, IS Robotics has built a number of innovative robots designed to detect mines, retrieve unexploded bombs, swim like fish—even walk up walls. The company's focus isn't solely on the military, though: IS Robotics recently signed a contract with Hasbro to develop interactive robots as future toys, and is working with the oil exploration industry and other industries. As president of the company and head of research, Greiner has been able to balance the company's business and research needs. "Helen is an innovator in technology, government research and business," says Rodney Brooks, director of MIT's Artificial Intelligence Laboratory and a co-founder of the company. In her position at IS, she is one of the leaders of an effort to develop networked robots that Brooks says will become "the eyes, ears and arms of the Internet."

JONATHAN IVE, 32 *Apple Computer*

Until recently, neither computer developers nor computer users paid much attention to the exterior of personal computers: What mattered was inside. This created an industry "where there is an obsession about product attributes that you can measure empirically," such as processor speed and hard disk size, says Jonathan Ive, vice president for industrial design at Apple. In 1997, though, Ive was charged by interim CEO Steve Jobs to design a radically different computer—with attention paid to style as well as content. The result of the work of Ive's design team was the iMac, a computer whose abilities were not so different from other computers, but whose design set it apart from any previous PC. Its colorful translucent case captured the interest—and pocketbooks—of millions; the design has inspired the sincerest form of flattery from makers of computer peripherals and, more recently, rival PC makers. Apple recently unveiled their latest design, the iBook, a laptop version of the iMac. While Ive's work helped Apple distance itself from the pack, that wasn't the primary purpose for his group's innovative design, he says. "Our goal wasn't just to differentiate our product, but to create products that people would love in the future."

WILLIAM MERCER MCLEOD/COURTESY OF APPLE COMPUTER, INC.

WEBB CHAPPELL

JOE JACOBSON, 34
MIT Media Lab

Electronic books hold great promise as a better way to read, but because of the limitations of display technology, they have lower resolution than the printed page, and thus are tough on the eyes. That may change thanks to the work of the Media Lab's Joe Jacobson. He and his group have developed a system using "micro-spheres"—two-toned particles about the size of grains of laser toner—embedded in a sheet of paper to display text and graphics. A conductive, transparent "ink" is used to flip the microspheres into the correct position, all controlled by a microprocessor printed directly onto the paper. In 1997 Jacobson co-founded a startup, E Ink, to commercialize the technology. Its first product, large signs that can display changing messages, was put to use in J. C. Penney stores this year. In addition, the ability to print microprocessors on paper and other surfaces could drastically change computing. "This technology puts forth the possibility of completely remaking both the chip industry and the fundamental way in which we make high technology devices," claims Media Lab director Nicholas Negroponte.

STEVEN LEEB, 33 *MIT*

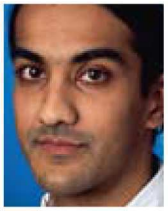
Getting complex machines to work well is tough enough; getting machines to work together intelligently is much more difficult. Steven Leeb is attacking this problem in several areas of a field known as "mechatronics": a combination of mechanical engineering, electronics and intelligent computer control. Leeb's forays into mechatronics could ultimately pay off in a remarkable range of fields: from artificial muscles to drug delivery to control of electricity and lighting in buildings.

On the biomechanical side, Leeb and his colleagues have developed gel polymers in which ferromagnetic materials are embedded. The polymers contract when exposed to magnetic fields, rendering them useful for artificial muscles and drug-delivery systems; related gels might be used to make braille and 3-D displays. Leeb has also developed a technique called nonintrusive load monitoring, a way of determining the major electrical loads in a building from measurements made only where the current enters the building. This is not only a simpler way to collect such data, but one that opens the way for intelligent power controllers and quality monitors. "I am enjoying just watching all of the neat stuff that comes out of Steve's lab," says colleague Jim Kirtley. "Steve Leeb has already had a major impact and promises to be very influential in the future."

AKHIL MADHANI, 31
Walt Disney Imagineering

If robots are to play a larger role in our lives, we will need to make them more dexterous and responsive. Akhil Madhani has been a leader in this pursuit since his days as a graduate student in MIT's Artificial Intelligence Lab.

As his doctoral project, Madhani created "Black Falcon," a robot that performed surgery under the command of a surgeon at a remote location. Although the military had been working on "telesurgery" for some time, Madhani's system represented a significant advance because it was able to do minimally invasive surgery (MIS)—a widely used technique in which the entire operation is carried out through a small incision. What's more, Black Falcon improves on conventional MIS, because it can reach into areas of the body that would be difficult for a surgeon alone to reach. The obvious potential of this system hasn't been lost on the private sector: Intuitive Surgical has licensed it for commercial applications.



In the meantime, however, in one of the boundary-crossing transformations that characterize contemporary innovation, Madhani has moved on to Walt Disney Imagineering, where he is working on what he will describe only as "next-generation, interactive robotic characters."

THAD STARNER, 29
Georgia Institute of Technology

These days, computers are everywhere. So far, they've kept their distance from our bodies, but what happens when computers become part of us, attached to our bodies like clothes or eyeglasses? That's a question Thad Starner has been asking—in practice—since 1993, when he developed his first wearable computer system. Wearable computing, a hot field in which Starner is a pioneer, changes our relation to computers; they become part of the environment, feeding us information as we interact with people and objects.

SAM OGDEN

Starner has been wearing his device much of the time since 1993, modifying the system as he goes. He's created an open hardware platform for wearables, dubbed "Lizzy," and software to make the most out of a computer that is always on and in contact with the wearer. Starner "has that rare combination of skills in theory, innovation, and sheer drive to make him, in my mind, the quintessential researcher," says John Makhoul, chief scientist at BBN Technologies.

MAJA MATARIC, 34
University of Southern California

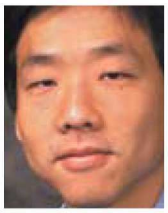
The human capacity for working together in groups is deeply rooted in our evolutionary history and we often take it for granted. Robots are starting to get some of that same capacity thanks to Maja Mataric, director of USC's Robotics Research Laboratory. Mataric and her students have been developing techniques to enable groups of robots to communicate with one another, coordinate activities and even learn from one another. Examples: Two robots using algorithms her group developed to cooperate in an effort to move a box, groups of robots working together to move in formation, groups that learn "social rules" such as sharing information and yielding to one another. "I cannot think of a single paper dealing with group robotics which does not refer to Dr. Mataric's work," says George Bekey, founder of USC's robotics program.

TODD C. MOWRY, 33 *Carnegie Mellon University*

Can a computer chip be too fast? Maybe, if the CPU is much faster than the memory chip. As a result, the CPU must wait for new data to be loaded from memory, and the computer runs below maximum speed. That creates a problem for computer designers. A brute-force solution is to develop faster memory chips, but some designers are looking for more elegant and economical ways to improve performance. One such designer is Todd Mowry.

As a graduate student at Stanford, Mowry came up with one solution: "prefetching" data from memory before the CPU required it, so it would be instantly available when needed. He designed algorithms to determine what data the CPU was likely to want next and make it more quickly accessible by the CPU. Today, as a professor at Carnegie Mellon University, Mowry is working on the development of single-chip multiprocessors: one large chip capable of performing multiple operations at once, using similar techniques to maximize performance. "Todd Mowry is one of the truly outstanding young computer architects in the world today," says Forest Baskett, chief technology officer at SGI. Mowry's work, he believes, is "dramatically improving the effective performance of real applications on today's microprocessors and memory systems."

MARK YIM, 34
Xerox Palo Alto Research Center (PARC)



Robots are expensive. Mass production would make them cheaper, but standardized robots may not be able to perform specialized tasks. What if, instead of mass-producing robots, you could mass-produce *parts* of robots and assemble them into the appropriate forms? Mark Yim is at the forefront of this approach, "modular robots," in which many small, identical robots are assembled to form one larger unit. As a graduate student at Stanford, Yim built Polypod, a robot composed of only two different types of modules that was able to move like a Slinky, an earthworm, or a caterpillar. At Xerox, he's developed a successor, PolyBot, that changes from a rolling loop traveling across flat terrain to an earthworm moving over obstacles. Yim's goal, though, is far more complex: systems of hundreds to millions of small robots that can reconfigure themselves into the desired form. Such "morphing" robots could become the ultimate tool, reshaping to fit the needs of the job at hand.

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Handicapping the Future

Picking 100 young people who exemplify the spirit of innovation takes a year, a lot of help from Nobel Prize winners—and some judgment calls.

How do you go about picking 100 people who personify the spirit of innovation? It's not easy, as the editors of *TR* discovered when we set out to celebrate our 100th year of publication. We had decided that the focus in the issue would be on the future—and that meant on youth. Our first task was to determine what we meant by young. After spirited discussions, we settled on a cutoff: Our innovators would all have 35th birthdays falling on or after January 1, 2000.

Having settled that thorny issue, we set out to find candidates. Every member of the staff had ideas. But we didn't want this to be an inbred process, so we issued a call for nominations in the pages of *TR* and on our Web site. Names came flooding in. To make sure we weren't missing anybody, we commissioned Brad Stenger, who in real life is a Georgia Tech graduate student in interface design, to beat the bushes. Ultimately we received close to 600 serious nominations.

The editors pored over the submitted dossiers, comparing the virtues of this remarkable assemblage of overachievers. We culled the top 200 nominees for consideration by our Panel of Judges (see box below)—a distinguished group that includes three Nobel Prize winners, the presidents of two of the world's best science and engineering schools, the head of the NASDAQ stock exchange, some of the country's sharpest venture capitalists, and other distinguished observers of cutting-edge technology.

We gave each judge about 30 nominees to evaluate, based on his or her areas of interest and expertise. Some did their evaluations in hard copy, others on a specially designed online database set up by *TR* Webmaster Jeff Foust. We encouraged the judges to think not just about the candidates' accomplishments but also about their potential to make an impact in the future. Each judge had a different method of evaluation, some more formal and explicit than others.

Caltech president David Baltimore, for example, reports that his evaluation method closely resembled the admissions process at his high-powered school. He looked first for "the usual stuff"—educational background, fellowships and recommendations. Then, says Baltimore, he looked for "unusual initiative, unusual creativity, unusual accomplishments. ...Even with these requirements it was an impressive group. Gives me faith in our educational system that we produce so many exciting people, even if the main contribution of the system is to not turn them off."

Bob Metcalfe, inventor of Ethernet and founder of 3Com *(see "Invention Is a Flower, Innovation Is a Weed," p. 54)* offered

Panel of Judges

Dr. David Baltimore
President
California Institute of Technology
Nobel Laureate, Medicine - 1975

Mr. John Benditt
Editor in Chief
Technology Review

Mr. Alfred R. Berkeley
President
NASDAQ/AMEX

Dr. Anita Borg
President and Founding Director
Institute for Women & Technology
Xerox Palo Alto Research Center

Dr. Morris Chang
CEO
Taiwan Semiconductor Manufacturing Company

Prof. Michael Dertouzos
Director, Laboratory for Computer Science
Massachusetts Institute of Technology

Mr. John Doerr
Partner
Kleiner Perkins Caufield & Byers

Mr. R. Bruce Journey
Publisher/CEO
Technology Review

Ms. Ellen Knapp
Chief Knowledge Officer & CIO
PricewaterhouseCoopers

Dr. Robert Langer
Kenneth J. Germeshausen Professor of Chemical and Biomedical Engineering
Harvard-MIT Division of Health Science and Technology

Dr. Robert M. Metcalfe
Technology Pundit
Vice President, Technology
International Data Group
Inventor, *Ethernet*
Founder, *3Com*

Dr. Nicholas Negroponte
Director, Media Laboratory
Professor of Media Technology
Massachusetts Institute of Technology

Dr. Arno Penzias
Venture Partner
New Enterprise Associates
Nobel Laureate, Physics - 1978

Ms. Kim Polese
President, CEO & Founder
Marimba Inc.

Dr. Diana Garcia-Prichard
President
Center for the Advancement of Hispanic Scientists and Engineers

Dr. Judith Rodin
President
University of Pennsylvania

Dr. Phillip A. Sharp
Professor and Head of the Department of Biology
Center for Cancer Research
Massachusetts Institute of Technology

Mr. Alan G. Spoon
President
The Washington Post Company

Mr. Ray Stata
CEO
Analog Devices

Mr. Anthony Sun
General Partner
Venrock Associates

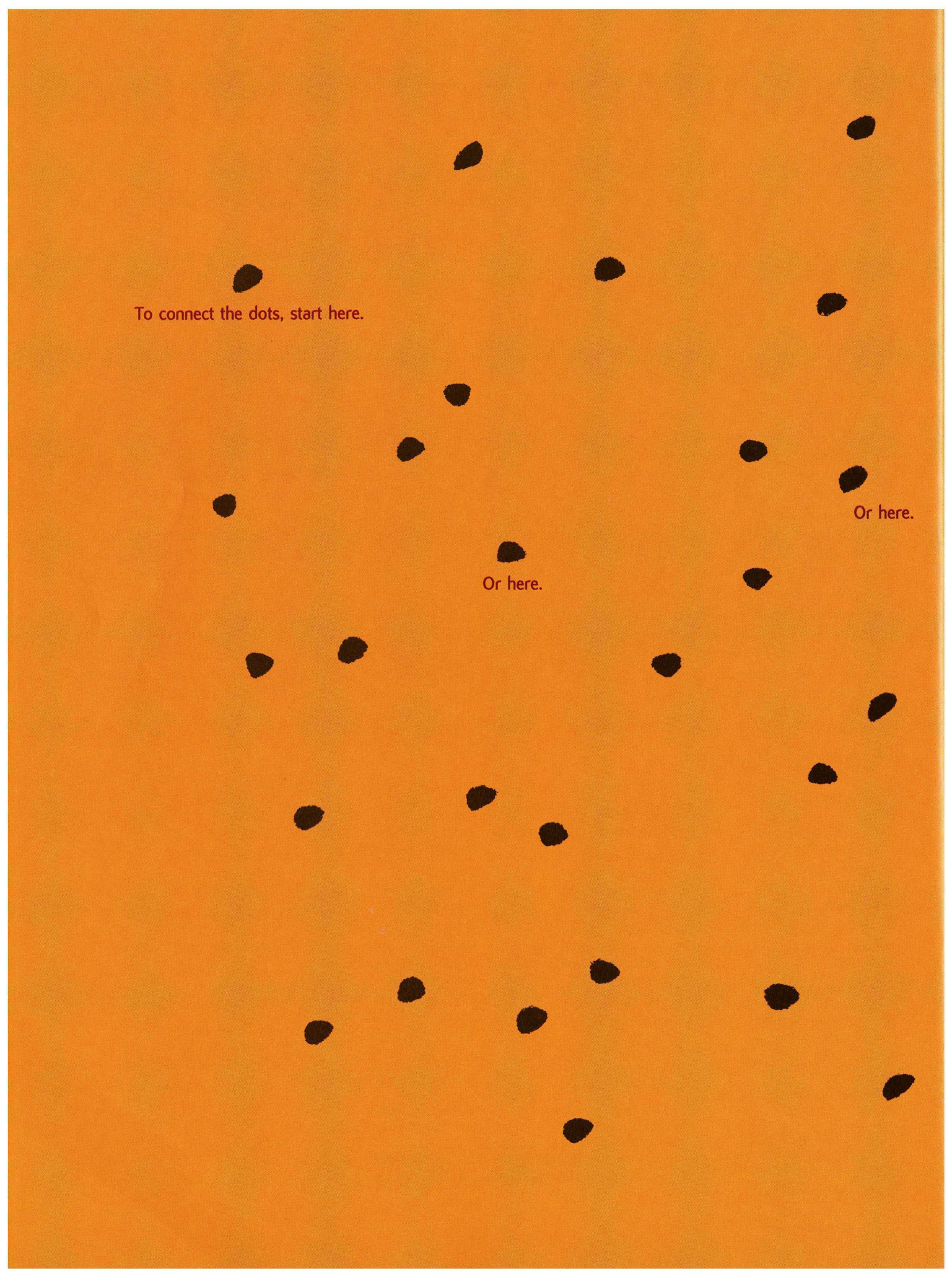
Dr. Charles M. Vest
President
Massachusetts Institute of Technology

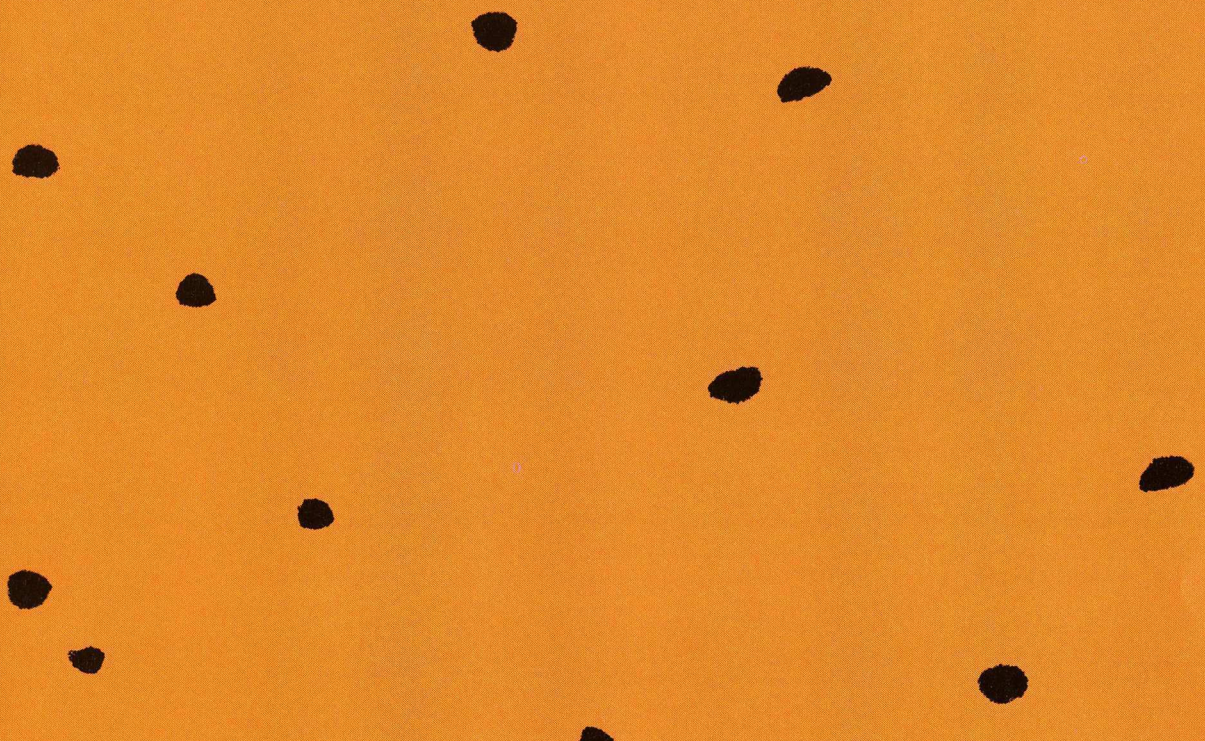
Mr. Larry Weber
Chairman/CEO
Weber Public Relations WorldWide

Ms. Ann Winblad
Partner/Co-Founder
Hummer Winblad Venture Partners

Dr. William A. Wulf
President
National Academy of Engineering

Mr. John Yochelson
President
Council on Competitiveness


To connect the dots, start here.
Or here.
Or here.



Or here.

You're a kid. You connect the dots any way you see fit.

You grow up, go to school. You learn to start where they tell you to start.

Now we're telling you to start anywhere you want again. Who do you listen to?

Let's just say this. Without going outside the lines, we never would have been able to take CDMA technology (Code Division Multiple Access—you won't be tested later), equip it with 4.4 trillion security codes, adapt it for digital phones and basically change an industry.

Because at QUALCOMM, it's amazing what you can come up with when you realize your mind's a very fun place. And you should visit. Go brain go.™

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Here's something else we dreamed up:

You may think it's just a thin phone, but it can also access the Internet and work as your pager.* Inside, its built-in lithium-ion battery allows you to leave the phone on standby for days. And, at barely over four ounces, it also has the ability to make you forget it's in your pocket. And, since we obviously dream in color, the QUALCOMM thin phone comes in a range of attractive shades. Further proof that what's inside your head may surprise you. Go brain go.™

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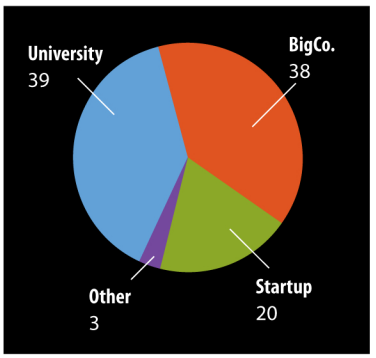
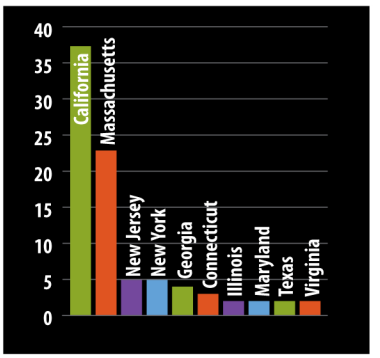
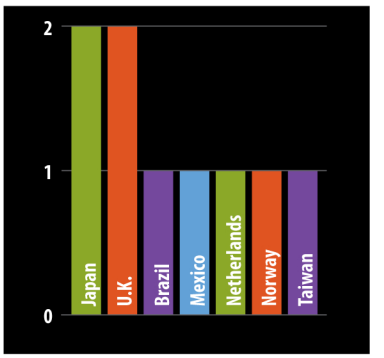
Please check with your local carrier for phone color availability. *Depending on services available from your carrier.

Hotbeds of Innovation

The TR100 come largely from the private sector (left). California dominates among states in the United States—with Massachusetts a strong second (middle). Japan and the U.K. are the leaders abroad.







a telegraphic listing of his criteria: "signs of early success, some sign of a struggle, some sign of interim approval from the real world, something exciting, something big."

John Yochelson, president of the Washington, D.C.-based Council on Competitiveness, said the evaluation process forced him to consider "the range of strengths that an innovator must have." Yochelson said he concluded, reading the nominees' files, that it would be "too much to expect any single person to have the full set of tools: brilliance in the lab; the capacity to develop a new product or service; entrepreneurial flair [and] the ability to change the policy environment in which innovation takes place." Yochelson added, however, that he looked for candidates who had more than one area of real strength—and that most of his top choices had at least two.

Formally evaluating the candidates wasn't the only significant contribution the judges made to this special issue. While the Panel of Judges examined the dossiers, Editor in Chief John Benditt and *TR*'s Publisher and CEO, Bruce Journey, had a memorable encounter with one judge, Arno Penzias, Nobel Prize winner and former director of Bell Labs, at a restaurant on the San Francisco waterfront. Penzias, now a venture capitalist, brought a valuable perspective.

Penzias argued persuasively that we should divide the TR100 into groups corresponding to the most important areas of technology covered by the magazine. After that, he said, we could interview the winners in each group and use their perspective to identify significant trends. Penzias' plan de-emphasized the "ranking" aspect of the project and stressed the intrinsic interest of what's going on in these fields. It made sense, and we adopted it.

Not long after that session on the Embarcadero, the judges finished their job and the editors of *TR*, in conjunction with TR100 Coordinator Stenger, settled down to the task of picking the final 100. It was a difficult job, since there were so many obviously qualified candidates. At the last minute, tough choices had to be made—for example, we had to make sure that we weren't overwhelmed by trendy areas such as e-commerce.

Penzias argued for interviewing the TR100 about future trends and summarizing the results, field by field.

Then, as we interviewed the TR100 for their profiles and the trends stories Penzias had proposed, two striking themes emerged repeatedly, and we decided to incorporate them into the final product: the ease with which young innovators pass back and forth between academia and corporations, and the remarkable nature and scale of today's technology collaborations.

Finally, using photos gleaned from the TR100 themselves, we put this package together and finished it by mid-September, about a year after hatching the idea. From putting together this impressive group we've learned a great deal that will help guide our coverage of technology's cutting edge. We hope you will learn just as much by reading this issue, which looks to the future as it celebrates our first century of publication.

Special Thanks

The editors of *TR* would like to offer particular gratitude to several people who aren't on the *TR* staff but who, as "Vassar Street Irregulars," played essential roles in the publication of this special issue.

Alexander Jacobs, fact checker for the TR100 section, ensured that 100 birthdates were correct and affiliations were accurate, and checked untold amounts of additional minutiae.

Jonathan Kreuze, jazz guitarist and aspiring lawyer, took on a very large load of profiles and handled them very capably.

April Paffrath served as Managing Editor for this issue, supervising, with exquisite precision, the monstrous task of getting the issue to the press on schedule.

TR 100 Index

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

CONGRATULATIONS

TR100

Technology Review and the sponsors of the TR100 congratulate each and every member of the TR100 on being selected as innovators of the future.

To see a listing of the TR100 and read about how they were selected, look to the left.

Lycos will find exactly what you want. And then some.

Lycos is your Personal Internet Guide to anything—and everything—you're looking for on the Web.

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JAMES YANG

MIXED MEDIA

Software Sea Change

Why should you buy applications when you can rent them?

I JUST BUILT A FULLY FUNCTIONAL E-COMmerce Web site, and I didn't have to acquire a Web development program to do it. In fact, I didn't use any software residing on my computer at all. Instead, I built the whole thing online at SiteMatic.com.

Sure, my new site is simple—it doesn't have the bells and whistles I could have added by hand or with a Web-design program such as Microsoft FrontPage. But it's an interesting example of a trend that promises to change the way people use and think about software. Rather than existing as products, software is becoming a service. Instead of purchasing application programs, people are accessing what they need over the Internet. Renting, not buying.

SiteMatic represents the latest incarnation of the new model—called "hosted applications"—which began with the wildly popular Web-based e-mail services such as HotMail *(see p. 106)*. Today, tens of millions of people use these services, and traditional software companies are leaping onto the hosted-app bandwagon with so-called "application service providers," or ASPs, which charge customers via a service contract, a pay-per-use deal, or not at all, depending on the service.

ASPs are doing a brisk business, and Forrester Research in Cambridge, Mass., predicts the hosted-application market will top $6 billion by 2001. Though the general public knows of online e-mail and calendaring services and the little mortgage calculators, games, widgets and applets they find on the Web, the bulk of today's ASP market is actually in expensive, specialized programs for giant companies. Corporations pay hefty rental fees for these applications because the ASP covers all the hassles—from installation to maintenance and upgrades.

Mainstream office applications have also begun moving to the hosted model. Late this summer Sun Microsystems bought tiny German-based Star Division and announced StarOffice—a free suite of hosted office productivity

applications (word processor, spreadsheet, scheduler, database and presentation programs) compatible with the Microsoft Office file formats. In response, Microsoft announced it was working with partners to host Office 2000 applications online.

Despite the potential conveniences, relying on hosted applications isn't a simple decision. The big advantage right now is that most consumer-oriented hosted applications are free, not for rent—ASPs typically support the services through advertising sales or use them as loss leaders for other services. That's likely to change as better techniques evolve for charging consumers piecemeal for their use of the software.

Even when pay-per-use pricing kicks in, renting may remain a better deal for occasional users, since there's no need to invest cash and computer resources in software that might sit idle for months. Just as important (for both occasional and frequent users) is the fact that the host company takes care of maintenance and upgrades—you'll never have to worry about configurations or whether you've got the latest version. Finally, if you use more than one computer, you won't need multiple copies of your programs or have to deal with platform incompatibilities. Hosted apps are available anywhere there's access to the Internet and they run in all different browsers, sporting the same familiar look and feel.

Hosted applications have some serious drawbacks, though. Obviously, they work only when you're connected to the Internet. No connection, no application. And their performance depends on the speed of the connection—try accessing most ASPs with a dial-up modem and frustration is the only thing that happens quickly. What's more, using hosted applications puts you at the mercy of the host. If the ASP has problems, you're out of luck, even if your computer is working perfectly. HotMail and Excite Mail, for example, have had some widely publicized reliability difficulties.

Ceding control to the host has some other, subtle implications. If software lives on your computer, it's up to you to decide whether to buy the new upgrade when a new version is released. But what if you don't want to upgrade? What if the latest version is still unstable? Or costs more? If you're using a rented application, you're going to be upgraded—ready or not—when the ASP decides to upgrade.

The advent of rental apps doesn't mean the box of software you just brought home is a dinosaur. For now, many people will want to own their software—especially programs they use frequently or to which they have sensitive data attached.

The real trick for the folks offering the applications will be to give the programs the power of their desktop equivalents, and make them simple enough to be used once in a blue moon. Then there must be an easy, efficient way for people to pay a small fee each time they use the software. When software developers straighten out those kinks, the stack of dusty software boxes on your bookshelf could finally start to shrink.

—Fredric Paul

An ASP Sampler

- **Bigstep.com:** Web site building, e-commerce
- **Email.com:** E-mail
- **Homefair.com:** Suite of tools for people moving to new cities
- **Hotmail.com:** E-mail
- **Sitematic.com:** Web site building
- **StarOffice** (www.sun.com/staroffice): Office suite, including word processor, spreadsheet and presentation programs
- **Yahoo! Calendar** (www.calendar.yahoo.com/): Appointment calendar

Computer Animation Comes Alive

Computer animation is as pervasive as rock and roll these days—on television, in the movies and almost everywhere else you look. But while music fans have long had "greatest hits" albums to enjoy at their leisure, anyone curious about the origins of computer graphics could only view them in rare conference or museum presentations. Now there's a video that could easily be called "Computer Graphics' Greatest Hits: The 1970s."

The two-tape compilation (actually called "Filmography of Computer Animation 1960-1980") is a special edition in an ongoing roundup of state-of-the-art graphics published by the Association for Computing Machinery's Special Interest Group on Computer Graphics, or SIGGRAPH. But this nearly four-hour-long collection focuses mainly on works produced during the 1970s, a time of "explosive growth in computer animation," according to the collection's curator, Judson Rosebush.

For $180, viewers get a trove of innovative demos and art pieces. Ed Catmull and Fred Parke's "Hand/Face" (1972), for example, shows the first computer animations of human features; a hand waves and faces emote in crude black-and-white renderings with blocky surfaces—after hours of off screen computer rendering for each frame. This ingenious feat, achieved on computers with the power of some of today's calculators, paved the way for the "virtual human" technology that's now starting to populate movies with synthetic actors.

Another staple of today's digitally animated visual world—real-time interactive color—debuts in "The Last SuperPaint Demo" (1977) by Dick Shoup, his early version of the Paint programs kids routinely use today. And if you've ever wondered where those annoying "flying logos" on TV station IDs came from, take a look at their precursors, "Television Titles" (1979); these were among the first commercial applications of computer animation, created by Rosebush's own pioneering Digital Effects firm.

Rosebush admits that this collection is hardly definitive; rights problems kept a number of classic pieces out of it. But to dig into the roots of the computer-generated visuals that have grown up all around us, there is no substitute for this anthology.

—Steve Ditlea

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

Innovator's Breakfast Series

MICHAEL DERTOUZOS

TIM BERNERS-LEE

CHERRY MURRAY

ERIC RAYMOND

A unique breakfast series featuring the world's leading innovators, straight from the pages of *Technology Review*, MIT's Magazine of Innovation. Now in its second season, this series offers senior executives, venture capitalists, MIT faculty, and entrepreneurs alike a rare opportunity to converse with some of the most important thinkers of the Information Age, in an intimate setting, at the heart of the MIT campus.

Recent speakers have included MICHAEL DERTOUZOS, Director of the Laboratory for Computer Science at MIT, TIM BERNERS-LEE, Inventor of the World Wide Web, CHERRY MURRAY, Director of Physical Science Research for Lucent Bell Labs, and ERIC RAYMOND, Linux guru and leading authority on Open Source Software.

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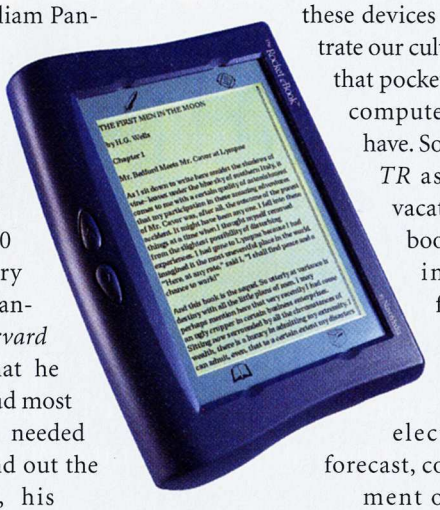
www.techreview.com

PAGES | BY WADE ROUSH

A Genuine Button-Pusher

Electronic books offer efficiency, economy and convenience —and they don't alter the fundamental nature of reading

EVERY OTHER YEAR, HARVARD UNIVERSITY awards the Philip Hofer Prize to the student with the best book or art collection. This year William Pannapacker, a doctoral student in the history of American civilization, took second place (worth $1,000) for his collection of some 3,000 books by 19th-century American authors. Pannapacker told the *Harvard University Gazette* that he will probably never read most of the volumes, but needed them anyway, to round out the collection. Indeed, his assortment includes six rare editions of Walt Whitman's *Leaves of Grass* and more than 100 biographies and commentaries on the poet—more than even a grad student could stomach. "Once you get so far into it, it's hard to get out," Pannapacker said. "After buying 100 volumes, it's hard not to buy those next few volumes."



NuvoMedia's Rocket eBook

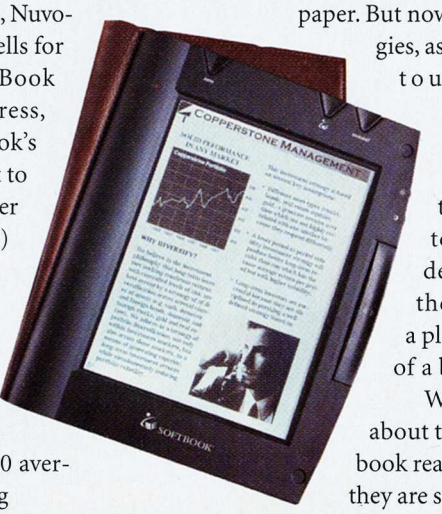
When I was a graduate student at MIT, I worked part-time as an antiquarian bookseller's assistant. The experience taught me that Pannapacker has plenty of fellow addicts. They can be amateur collectors such as the late industrialist Bern Dibner, whose personal library of 40,000 volumes on the history of science and technology moved to MIT in 1993. They can be professionals who buy and sell books about narrow subjects (architecture, landscaping and fishing were my employer's specialties). Or they can be elite, acquisitive institutions such as Harvard, which adds hundreds of books a day to its academic libraries, already the planet's largest. Book collecting, in other words, is hardly an unusual or new phenomenon. Books have always existed not merely to be read, but to be possessed.

But that may soon change, thanks to a new technology for reading—the electronic book. Once a few bugs are fixed, these devices will probably infiltrate our culture in the same way that pocket calculators, laptop computers and cell phones have. So when the editors of *TR* asked me to take a vacation from my usual book reviews and think instead about the future of reading, I decided to spend a month experimenting with an electronic book. My forecast, counter to the argument of some critics, is that the new technology will not fundamentally alter the *experience* of reading, or diminish the role of written documents in our culture. It will, however, force bibliophiles everywhere to rethink the relationship between the tangible objects we call books and the ideas they contain.

Electronic book readers, paperback- or tablet-sized devices with high-resolution displays, hit the consumer market in 1998. Like PCs, they are rapidly coming down in price; one model, NuvoMedia's Rocket eBook, sells for about $300. (The SoftBook Reader, by Softbook Press, goes for $600; Everybook's EB Dedicated Reader, set to debut in the fourth quarter of 1999, will cost $1,600.) The readers can be loaded with new books, erased, and reloaded as frequently as one wishes. The Rocket eBook's 32-megabyte memory is enough for 80 average-length novels. Buying the electronic edition of a book has become as easy as browsing the Web. I've been testing the Rocket eBook, and I find its heft, appearance and operation so similar to that of a real book that I frequently forget about the high-tech interface and lose myself in the narrative.

All of these facts point toward the same trend. Writing—the procession of little black marks that miraculously convey ideas from the mind of the author to the mind of the reader—is breaking free from its traditional medium, ink on pancakes of cellulose. Printing on paper is a highly evolved technology; the magazine you are holding is a marvel of forestry, chemistry, photography, typography and graphic design. When it comes to efficiency, economy and convenience, however, the electronic book is beginning to give paper some serious competition.

From a technical point of view, the new electronic book readers aren't spectacularly innovative. Graphical interfaces making it easy to manipulate words on the screen have been around since the 1970s. Electronic editions of books have been available on CD-ROMs and the Internet for years. And thanks to high-resolution monitors and software such as Adobe Acrobat, type on the computer screen has become nearly as readable as type on paper. But now these technologies, as well as batteries, touch-sensitive LCD displays and microchip memory capacity, have matured to the point that designers can use them to construct a plausible imitation of a book.

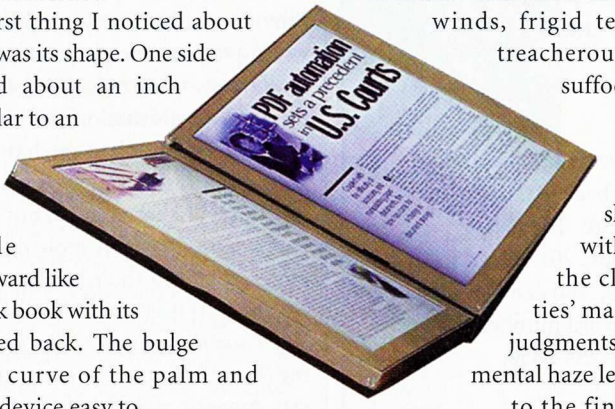


Softbook Press' SoftBook Reader

What's really new about today's electronic book readers, then, is that they are so "retro," looking backward to the tradition-

al book for design inspiration. Deanna McCusker, a user interface designer for the Rocket eBook, writes that NuvoMedia's goal in building the eBook was "to figure out how to preserve a book's bookness." They have succeeded.

The first thing I noticed about the eBook was its shape. One side is flat and about an inch thick, similar to an Etch A Sketch, but the other side bulges outward like a paperback book with its spine folded back. The bulge fits in the curve of the palm and makes the device easy to grip with one hand. The screen measures 7.6 cm by 11.4 cm (3 inches by 4.5 inches), the size of a small paperback, and the whole package weighs 616 grams (22 ounces), about as much as a 400-page hardcover. The overall feeling is highly booklike.



Everybook's EB Dedicated Reader

The eBook's most impressive features, however, are inside. The display's adjustable backlight emits a pleasing white glow that's the brightest I've seen in an LCD screen. The resulting contrast between text and background rivals what you would see in a newspaper or paperback. Pressing the eBook's "forward" and "back" buttons, positioned under the thumb, takes no more thought than turning the pages of a real book. Navigating within a text is simple, thanks to a bookmark function and a progress bar that lets you jump to any point in the narrative. And by pulling up the touch-sensitive keyboard, you can even add your own notations and search the text for specific words (for example, the first mention of a character in a novel). With the display at a medium intensity, the rechargeable batteries last about 20 hours. For people accustomed to laptop and cell-phone batteries that die in less than half this time, that's a strong selling point. (According to McCusker, the designers considered using smaller batteries to reduce the eBook's weight, but usability testers said longer battery life was more important to them than lighter weight.)

All of these features work together to make the device itself recede into the background, freeing the reader's mind to concentrate on the text. The first book I read using the eBook was *Into Thin Air*, journalist Jon Krakauer's account of a 1996 expedition to Mount Everest that left eight of his fellow climbers dead. As Krakauer described the horrendous winds, frigid temperatures, treacherous terrain and suffocatingly thin atmosphere near the peak, I was shivering there with him. And as the climbing parties' machismo, misjudgments and hypoxic mental haze led them closer to the final disaster, I read faster, staying up late one night to reach the end. The book is a genuine page-turner—or button-pusher, in this case—and I don't see how the hardcover edition could have been any more absorbing than the electronic one.

Since that first book, I've used the eBook to read the Constitution of the United States, *Common Sense*, *Northanger Abbey* and *Ethan Frome;* next up will be *Jane Eyre*. Absent from this list, you may notice, are any current best sellers. This brings us to the eBook's principal drawback: NuvoMedia's publishing model, which is cleverly designed to prevent the electronic piracy of copyrighted works, but which is also being used to squeeze big bucks from electronic book buyers.

New releases for the eBook are available only as specially encrypted files called RocketEditions. New eBook owners receive a "RocketID" number from NuvoMedia; before purchasing and downloading RocketEditions from an online bookseller, they must submit this ID, which is used to encrypt the book so that only their eBook can decrypt it. Public-domain works don't need to be encrypted, and electronic publishers such as Treeless Press offer them at low prices—from $1.50 to $6. But for the encrypted RocketEditions of most new books, the publishers and booksellers working with NuvoMedia, notably Barnes & Noble, charge the regular hardcover price. This despite the fact that books published electronically incur no typesetting, printing, binding, ware-

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Technology Review	JA99

15. Extent and Nature of Circulation		Average No. Copies Each Issue During Preceding 12 Months	Actual No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies (Net press run)		253,725	301,603
b. Paid and/or Requested Circulation	(1) Sales Through Dealers and Carriers, Street Vendors, and Counter Sales (Not Mailed)	22,067	25,638
	(2) Paid or Requested Mail Subscriptions (Include advertiser's proof copies and exchange copies)	195,435	235,711
c. Total Paid and/or Requested Circulation (Sum of 15b(1) and 15b(2))		217,503	261,349
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f. Total Free Distribution (Sum of 15d and 15e)		2,755	3,831
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	(2) Returns from News Agents	19,892	20,614
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16. Publication of Statement of Ownership
☐ Publication required. Will be printed in the ND99 issue of this publication.
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17. Signature and Title of Editor, Publisher, Business Manager, or Owner: R. Bruce Journey, Publisher, CEO — Date: 10/1/99

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housing or shipping costs, which typically account for 20 percent to 60 percent of a book's retail price.

Under this pricing system, the $300 eBook will never come close to paying for itself. Since I rarely buy best sellers, and I'm one of those "early adopters" who are willing to use new gadgets before all the kinks are worked out, I'm not overly distressed by the situation. At the very least, I can use my eBook to catch up on all the great works I should have read in college.

But will I get as much out of an electronic *Jane Eyre* as my more diligent classmates got from their Norton paperback editions? At least one critic thinks not. In *The Gutenberg Elegies: The Fate of Reading in an Electronic Age*, essayist Sven Birkerts suggests that literature loses something in the translation from ink to electrons. Words on a screen, Birkerts wrote, "have a different status and affect us differently from words held immobile on the accessible space of a page.... The word on a page is a thing. The configuration of impulses on the screen is not—it is a manifestation, an indeterminate entity both particle and wave, an ectoplasmic arrival and departure."

Birkerts, writing in 1994, was mainly talking about word processing and CD-ROM-based multimedia. Electronic books, however, were already on the horizon, and Birkerts was alarmed. Rejecting the argument that reading on screen is the same as reading on a page, he wrote: "The context cannot but condition the process. Screen and book may exhibit the same string of words, but the assumptions that underlie their significance are entirely different depending on whether we are staring at a book or a circuit-generated text."

Maybe it's a generational thing, but I have a hard time sympathizing with Birkerts' concern that digitized, transistorized words don't really exist. My entire PhD dissertation, completed the same year as Birkerts' *Elegies*, sits on an old 40-megabyte external hard drive that I can't access because I don't currently own a Macintosh, but I know that it's there and that it could be retrieved. I must report, moreover, that when I used the eBook to re-read the U.S. Constitution, "the assumptions that underlie [the] significance" of this timeless document didn't seem to shift much.

On a related point, however, Birkerts hits closer to the mark. As I observed at the outset, some books have a dual nature as things to be read—vessels to be emptied of their symbols and meanings—and as physical artifacts to be admired or collected for their historical value. A traditional paper book can be both of these things. An electronic book, Birkerts points out, can only be the first. He writes:

> In the contemplation of a single volume, or mass of volumes, we form a picture of time past as a growing deposit of sediment; we capture a sense of its depth and dimensionality. Moreover, we meet the past as much in the presentation of words of specific vintage as we do in any isolated fact or statistic. The [electronic] database, useful as it is, expunges this context, this sense of chronology, and admits us to a weightless order in which all information is equally accessible.

This is a valuable warning. With their increasing power and portability, appliances such as the electronic book are creating a global network of information. This information is so disembodied, however, that we frequently have few ways to judge its provenance or worth, and so we lose all sense of physical connection with the originator. As it turns out, you *can* judge a book by its cover.

As electronic books gain a following, especially in the world's centers of writing and thought, points of tension with the world of traditional books will no doubt develop. Imagine, for example, that a Harvard student with a Rocket eBook visits Barnes & Noble's Web site and purchases the RocketEditions of a hundred classic literary works. She puts just as much care into her selections as William Pannapacker, and then actually *reads* the books, resulting in a collection that genuinely reflects her intellectual passions. Would she have any chance of winning the Philip Hofer Prize? Should she? Is there something about the ink, the paper, the binding, the odor of a book that contributes to the ideas within? If not—if a book's essence is retained when its words are reduced to electronic bits—does this mean that our attachment to the leather-bound, dusty-smelling volumes of old is simply a kind of sentimental materialism? Either way, it may be time for some serious book re-viewing. TR

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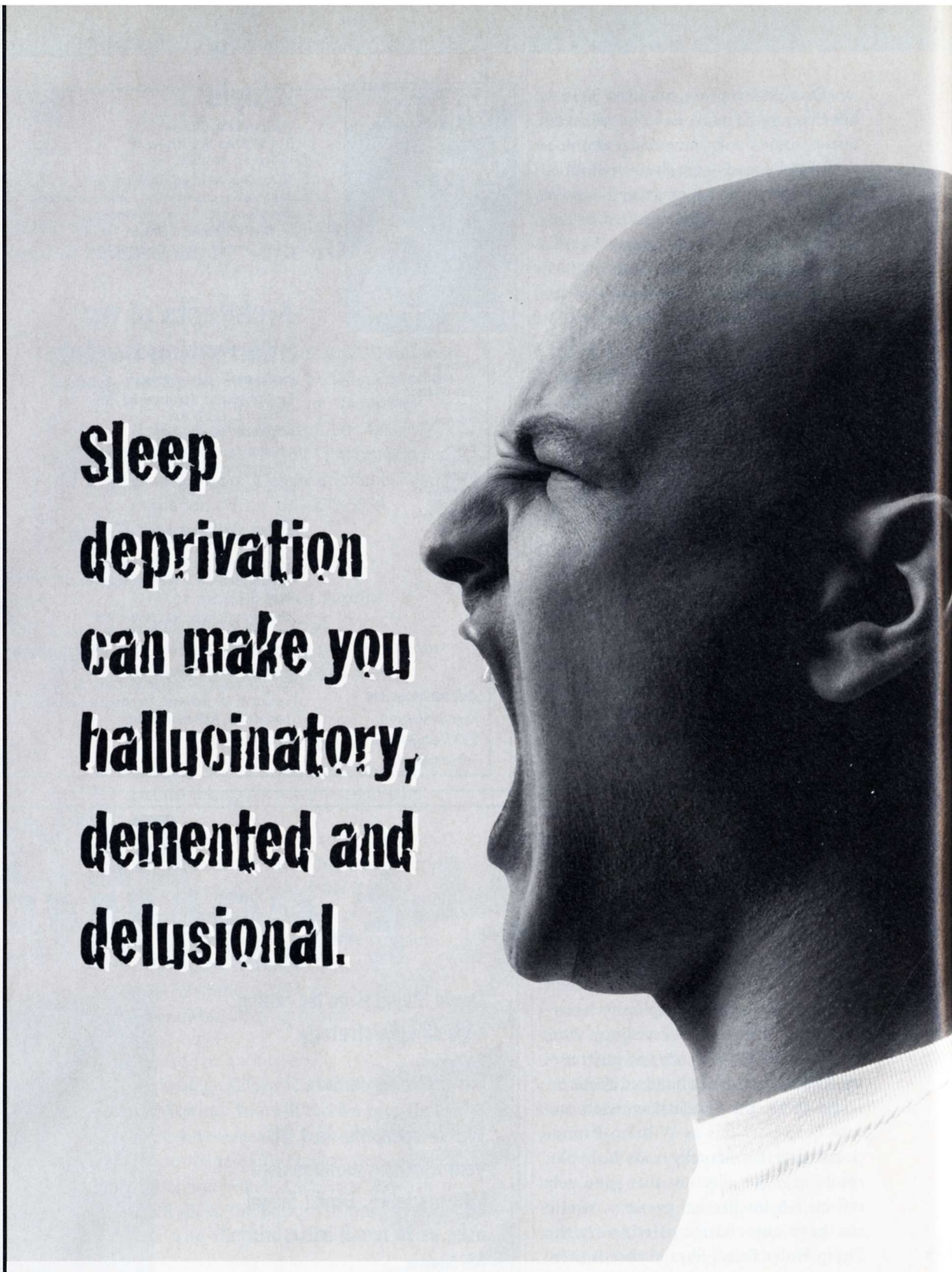

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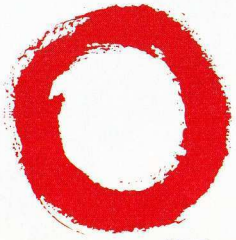

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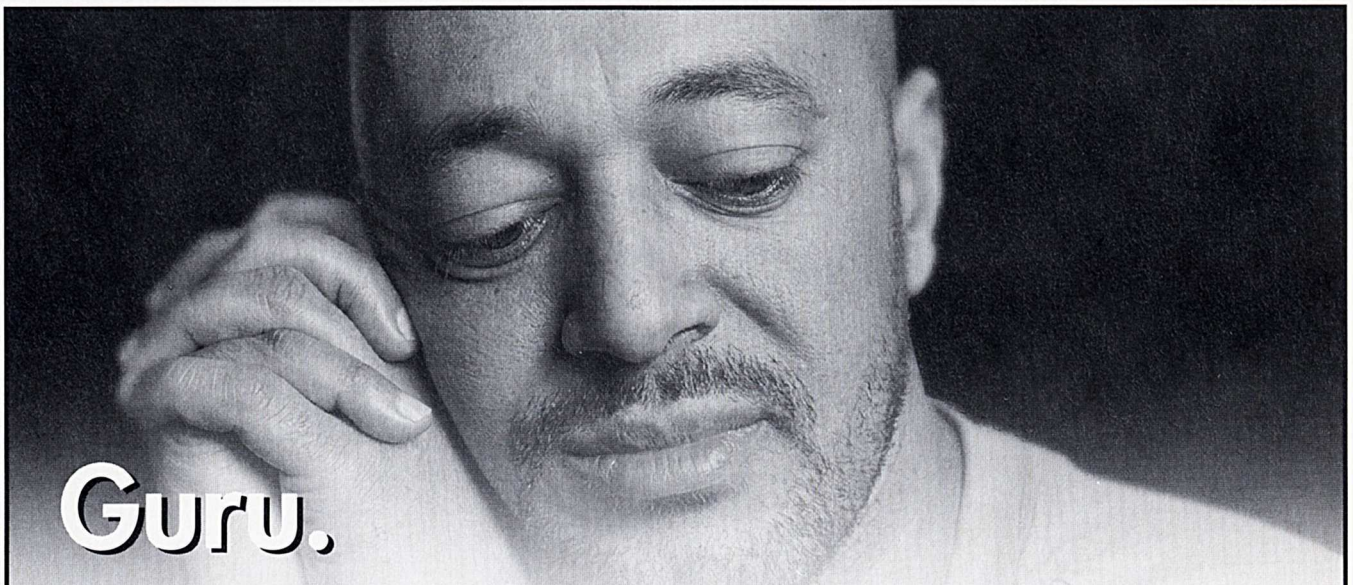

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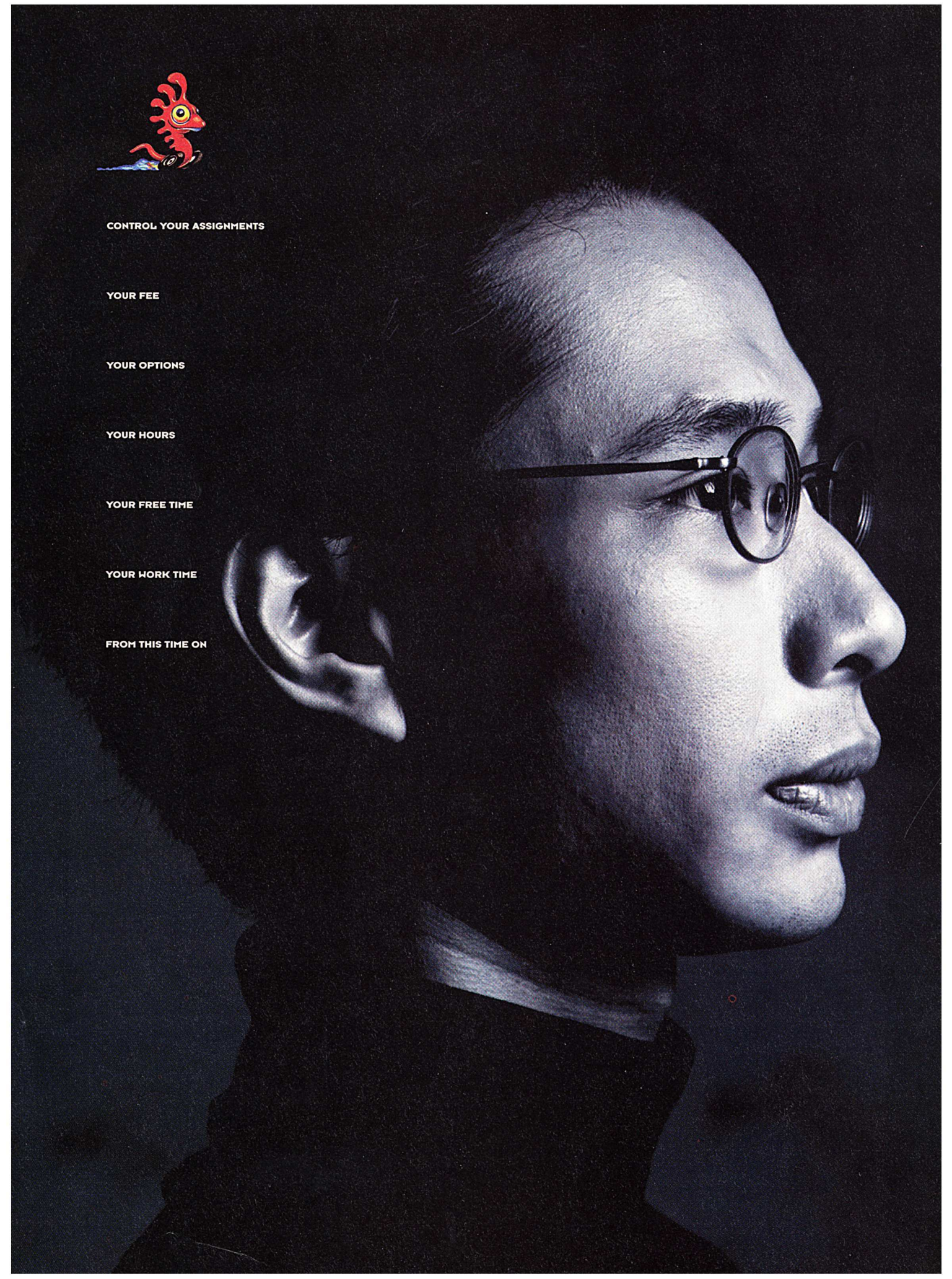
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The Terrible Century

Winston Churchill reminds us that technology can do great—and awful—things

In April 1949, Winston Churchill spoke before a crowd of 14,000 in Boston Garden for MIT's "Mid-Century Convocation." TR published the speech, excerpted below, the following month. As we look to a new century, we're mindful of the lesson Churchill learned in this one: The seductive "brain buzz" of technology must be tempered by ethical codes.

We entered this terrible Twentieth Century with confidence. We thought that with improving transportation nations would get to know each other better. We believed that as they got to know each other better they would like each other more, and that national rivalries would fade in a growing international consciousness. We took it almost for granted that science would confer continual boons and blessings upon us....

That is how we began the century. Science presently placed novel and dangerous facilities in the hands of the most powerful countries. Humanity was informed that it could make machines that would fly through the air....

...Fanned by the crimson wings of war, the conquest of the air affected profoundly human affairs. ...The whole prospect and outlook of mankind grew immeasurably larger, and the multiplication of ideas also proceeded at an incredible rate. This vast expansion was unhappily not accompanied by any noticeable advance in the stature of man, either in his mental faculties, or his moral character. His brain got no better, but it buzzed the more. ...Science bestowed immense new powers on man, and, at the same time, created conditions which were largely beyond his comprehension and still more beyond his control. While he nursed the illusion of growing mastery and exulted in his new trappings, he became the sport and presently the victim of tides, and currents, of whirlpools and tornadoes amid which he was far more helpless than he had been for a long time.

...Our...codes of honour, morals and manners, the passionate convictions which so many hundreds of millions share together of the principles of freedom and justice, are far more precious to us than anything which scientific discoveries could bestow. Those whose minds are attracted or compelled to rigid and symmetrical systems of government should remember that logic, like science, must be the servant and not the master of man. TR

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